GUIDELINES FOR SELECTION OF A SHIP BALLAST WATER TREATMENT SYSTEM

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Report delivered:
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Problem description

Background

Ballast water is the primary way that non-native species are introduced to various territorial waters, and in many cases it may have a major economical and ecological impact. As a consequence, IMO has introduced new rules covering the control and management of ship's ballast water. These new rules are not formally ratified, but are expected to come into effect from 2012 to 2017. The required measures to be taken will depend on each ship's ballast water capacity and the construction date of the ship.

Kristian Gerhard Jebsen Skipsrederi A/S (KGJS) is presently managing a fleet of more than 100 ships which mainly consists of General Cargo, Cement Carriers, OBOs and Suezmax and LR2 tankers. They also have an extensive new-building programme of more than 30 ships in total. KGJS is also ISO 14000 certified and aims to have a proactive approach to this, and as compliance with these new rules represents a considerable investment, they will define a policy and standard. KGJS has started a project for evaluating available systems, using a few reference ships from their fleet as a basis for a system evaluation prior to implementing the retrofit of the fleet.

Description of the task

The overall aim of the project is to develop a decision support tool that can be applied to a wide variety of ship types, sizes and sailing patterns in order to simplify the process of selecting a cost-effective solution for ballast water treatment systems.

The decision tool should consider parameters such as system size, footprint and design, maintenance routines, environmental aspects for the operators, estimated lifetime, and both operational and investment costs. Additionally a life cycle cost analysis, with respect to purchase, installation, maintenance and reliability should be conducted. This should be based on a set of generic systems characteristics representative for most of the commercially available ballast water treatment systems.

Objectives

a) Collect data from vendors and compare different vendor solutions for a ballast water treatment system.

b) Define a set of system design requirements based on the IMO convention and the vendor data for the commercially available systems

c) Develop a decision support tool utilizing the results of objective a) and b) and tailored to suit the specific classes of ship (age, size and type) found in the KGJS fleet.

d) Define generic and specific solutions for ballast water treatment aboard the various classes of ship in the KGJS fleet and perform a simple life cycle costs analysis and reliability study for a selection of these.

e) Give recommendations on how to inspect if these systems are in compliance with standards

Material

- Project report on ”Ballast water treatment technologies”
- Drawings and technical specifications for existing systems from equipment suppliers
- CAD drawings showing general arrangement and engine room layout for ships to be included in this study

The Master’s thesis will address the following points:

1. Ballast water treatment system requirements and specifications
2. Evaluation and comparison of commercially available systems, including service and maintenance requirements
3. Development and programming of a decision support aid for selection and optimization of a ballast water treatment system for selected ships, or group of ships, based on usage, age, capacity, rate of flow, etc.
4. Reliability and fault tree analysis for selected ballast water treatment systems
5. Evaluation of CAPEX, OPEX, and Life Cycle Costs
6. Decision Support System Users Manual and Documentation, with case studies
7. Conclusions, discussion and recommendations

Within 14 days of starting the assignment the candidate shall send the department a detailed plan for carrying out the work, for evaluation and discussion with the supervisor/contact persons. The thesis should be formulated as much as possible as a research report, with abstract, conclusions, reference list, contents. Etc.

When preparing the thesis the candidate should make the text easy to read and it should be well written and systematically laid out. To help when reading the thesis it is important that the necessary references are made from corresponding points in the text to tables and figures and also to material from external literature. When grading the thesis emphasis is put on thorough processing and analysis of the results, and that the results are presented graphically or in tables in a well arranged way and are fully discussed, and that appropriate conclusions are drawn.

The work often forms part of a larger investigation at the department, which reserves itself the right to use all results in the master's assignment in connection with teaching, publications or other activities.

The thesis is to be submitted in 2 examples. Additional copies to co-supervisors/contact persons from cooperating companies shall be agreed with and delivered directly to them. A complete copy of the thesis shall be delivered to the department on a CD-ROM in Word-format.

This master assignment is being carried out in cooperation with Kristian Gerhard Jebsen Skipsrederi AS, where the contact person is Willy A. Reinertsen

Preface

This project thesis is a mandatory project part of the Master Programme in Marine Technology at The Norwegian University of Science and Technology. This project is an introductory work which forms the basis for the Master thesis in the final semester. Professor Maurice F. White at NTNU has acted as teaching supervisor during.

I would like to thank those who have helped me in the work on this project. First of all I would like to thank Mr. Willy A. Reinertsen and Sverre Grønn and others at Kristian Gerhard Skipsrederi AS, for all the help and input provided during my work. Mr. Geir Høvik Hansen at the Norwegian Coastal Administration for all his help understanding the IMO regulations and work, and Ms. Nicole Dobroski at the California State Lands Commission for all her help with understanding the California performance standards and procedures.

It should be noted that appendices are number after when they are referenced in the text, while appendices marked as (confidential) is in a separate booklet.

And finally I would like to thank Professor Maurice White for the help with typos and input during my work.

Trondheim, 14 June 2010

Magnus U. Berntzen

Abstract

The purpose of the thesis was to develop a decision support system for ballast water treatment systems, considering both technical and economical aspects of the system. This was done by developing a two part model, which considers both physical constraint given by the ship, and KPI analysis.

In order to test the model, it was applied on two vessels from KGJS fleet; MV Corrella Arrow, a 72.000 DWT general cargo ship, and a cement carrier that is currently being built in Vietnam. For both these ships the model identified 6 – 8 systems that were applicable, but by applying ship specific constraints and additional knowledge of the systems it was possible to eliminate several other systems. As a means to further eliminate systems, a detailed analysis was required.

When analysing the operational costs, it was found that installing a treatment system will increase the daily operational costs with $1 - $30, and increase the annual fuel consumption with 1 – 20 tons. This is negligible when compared to the installation and investment cost.

For the cement carrier it was that two systems were applicable to the ship; OptiMarin Ballast System and Hyde Guardian. Where Hyde Guardian be too large, OptiMarin Ballast system will have a higher cost. Simplicity have to be considered against cost.

For MV Corrella Arrow, WSE Unitor was found to be the best option. However, it should be noted that as the reactor unit is located before the ballast pumps, the negative effects it might have on the ballast pumps should be closely monitored after installation.

Nomenclature and abbreviations

Word	Description
Active Substance	Any substance or organism that has a general or specific effect on or against harmful aquatic organisms
GESAMP – BWWG	Group of Experts on Scientific Aspects of Marine Environmental Protection – Ballast Water Working Group
IMO	International Maritime Organization; an UN body
KGJS	Kristian Gerhard Jebsen Skipsrederi AS
KPI	Key Performance Indicator; a measure of performance, commonly used to define and evaluate how successful an organization or company is
MEPC	Marine Environment Protection Committee; an UN body
System	Unless otherwise specified, this will refer to a ballast water treatment system
UV	Ultra Violet; an electromagnetic radiation with a wave length shorter than visible light
WSE	Wilhelmsen Ship Equipment

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1 Introduction

1.1 Background

In 2004, IMO introduced "International Convention for the Control and Management of Ships' Ballast Water and Sediments", which is intended to address the ever growing issue of the introduction of non native species in waters all over the world. When this convention is ratified, all ships above 100 GT needs to have a water ballast treatment system installed.

Even though this convention is not formally ratified yet, the process of approving different systems and installing them is already ongoing. Kristian Gerhard Jebsen Skipsrederi AS (KGJS) have seen that this will be an important factor in the future and have chosen a pro active approach to the problem. They have already established a project group working on finding the best solution for all ships in their fleet.

Currently their ballast water project group is working on identifying systems that will be installed within 2011 as test systems for a further evaluation within 2012. Their primary goal is to standardize the systems used for the different segments of their fleet, and have a full scale implementation within 2016.

1.2 Work at hand

The primary purpose of this study is to develop a decision support model that can be applied to a wide variety of ship for a wide variety of treatment systems. The initial attempts on creating an automated process found that this was not feasible; the technology available is either too similar, or can be applied to the same ships.

This means that the decision process has to be divided into two parts. The first part is an automated process, which handles a few input data, and where it does a rough screening of the available systems. In this way you can easily exclude systems that are not applicable to the ship, and only performing a detailed analysis for those who might be.

The second part is more an engineering process, where more practical issues are addressed. This takes things like capital cost, installation cost, actual install areas and necessary engineering required into consideration. The purpose is to try to standardize this process and establish a set of guidelines and examples that can be used as a template to reduce the workload for each ship considered.

2 Regulations

2.1 Ballast water exchange standards

This chapter is a summary of parts of IMO's resolution A.868(20)[1]. Even if the rules are not formally ratified, they are expected to come into effect within a short period of time. The performance standards are divided in two; the first is meant to be transitional, called D1 ballast water exchange standard, or just D1. The actual performance standard, which requires a treatment system, is referred to as D2. This only requires operational changes; no additional equipment has to be installed on the ship. As seen from the table below, for ships already in operation there will be a transitional period, while for new buildings from 2009 and later it might be necessary to install a treatment system once the convention is formally ratified.

Keel laying	Ballast capacity	2009	2010	2011	2012	2013	2014	2015	2016	2017
Before 2009	< 1500 m^3	D1 / D2							D2	
	1500 m^3 - 5000 m^3	D1 / D2					D2			
	> 5000 m^3	D1 / D2							D2	
2009 - 2011	< 5000 m^3	D2								
	> 5000 m^3	D1 / D2							D2	
After 2012	All				D2					

Table 1: IMO timeline for compliance

The actual performance standard based off of the assumption that near coastal organisms will most likely not survive in deep water, and oceanic organisms will most likely not survive in shallow water. This means that the primary focus is on the location where ballast water is discharged, as most ballast water operations are done when the ship is either loading or unloading. The ballast water should be discharged in deepwater, or as far from shore as possible, preferably in open sea. In areas or situations where this is not practicable, regional requirements should be followed, especially in areas within 200 nautical miles from shore, i.e. inside the exclusive economic zone. In this case there might be designated areas given by the port state. Additionally at least 3 times the volume of the ballast tank should flow through the tank when changing or shifting ballast water during voyage. This is to ensure that most sediments and organisms are discharged during this operation.

IMO also states that it would be hard to control or inspect if the ships are in compliance with D1 regulation, as well as measuring the efficacy of these measures. As a way to ensure compliance IMO have developed a ballast water reporting form, that have to be provided to port state by request. This form contains information about ship, ballast water onboard and ballast water capacity, location of uptake of ballast water and which ballast water tanks that will be discharged in next port. IMO also recommends that each ship have a responsible officer that maintains appropriate documentation, and make sure the ship follow procedures for ballast water management. The ballast water reporting form will still be mandatory when compliance with the D2 standard is required.

When the Ballast water convention is formally ratified, the D1 regulation will be in effect for all ships with a keel laying before 2009. The easiest way to facilitate this change in operation is to produce proper procedure documentation and appoint a responsible officer on each ship that ensures that these procedures are followed.

2.2 Ballast water performance standard

This chapter is based on IMO resolution A.868(20), MEPC.173(58) – G2, MEPC.174(58) – G8 and MEPC.169(57) – G9. Ballast water treatment indicates a treatment process of ballast water. However, the regulations only focus on viable organisms discharged with ballast water. By a viable organism it is meant that the organism is able to reproduce and establish itself in the region it is discharged. The method you achieve the standard can vary from a chemical treatment process to a shore reception facility that ships discharges ballast water to, where it could be treated before being discharged to sea.

Category	IMO Standard
> 50 µm (Zooplankton)	< 10 viable organisms per m^3
10 - 50 µm (Phytoplankton)	< 10 viable organisms per ml
Bacteria	
Toxicogenic Vibrio Cholorae	< 1 cfu/100 ml or < 1 cfu/gram wet weight Zooplankton samples
E-Coli	< 250 cfu/100 ml
Intestinal Entercocci	< 100 cfu/100 ml

Table 2: IMO D2 Standards

Table 2 presents the current IMO D2 standards for ballast water treatment. There is no limitation to the method used to achieve compliance with the D2 standard. The only exception is treatment using an active substance. IMO defines an active substance as:

> a substance or organism, including a virus or a fungus that has a general or specific action on or against harmful aquatic organisms and pathogens.[2].

All active substances have to be approved by IMO, to ensure that the discharge of ballast water treated with an active substance have no harmful effects on the environment or human health. Whether or not a system uses an active substance is decided by the flag state, in some cases in collaboration with a classification society. The procedure of approval of ballast water treatment systems using an active substance is described in resolution MEPC.169(57), which is discussed in detail in chapter 2.3.

In addition to the necessary biological killing efficacy, there is also a need to install a sampling point for ballast water, preferably as close to the discharge point as possible. There are very detailed descriptions on how the flow should behave when approaching the sampling point and what equipment should be used. Main points are that no shear stresses or disturbance to the flow should be induced when diverting the sample from the main flow. This is to ensure that the sample is representative, i.e. no living organisms should be killed by the sampling procedure.

The resolution of most importance is Resolution A.868(20) ”Guidelines for the control and management of ships’ ballast water to minimize the transfer of harmful aquatic organisms and pathogens". The other 3 are merely guidelines for treatment systems, mostly in connection with the approval procedures.

Name	Description
G1 (MEPC.152(55))	Guidelines for sediment reception facilities
G2 (MEPC.173(58))	Guidelines for ballast water sampling
G8 (MEPC.174(58))	Guidelines for approval of ballast water management systems
G9 (MEPC.169(57))	Guidelines for approval of ballast water management systems making use of active substances

Table 3: Overview of IMO ballast water guidelines

Not all of these guidelines are interesting when it comes to the individual ships compliance, as it is fair to assume that a treatment system with type approval will perform according to the performance standard. It is also found that most vendors also supply, or can supply, a sampling system when purchasing a treatment system. However, if the vendor cannot supply a treatment system, the ship is still required to have one installed according to the G2 guidelines.

Currently there are 24 states (representing approximately 23% of the world's merchant fleet) that have ratified the ballast water management convention. The convention will enter into force 12 months after at least 30 states representing 35% or more of the gross tonnage of the world's merchant fleet ratify the convention [3] [4].

2.3 System approval process

This chapter is mostly based on resolution MEPC.174(58) [3] and MEPC.169(57) [5]. The IMO approval process is long and complicated, and not easy to understand at a glance. The most important thing is that they differentiate between systems using an active ingredient and systems that do not use an active ingredient. As mentioned in chapter 2.2, an active ingredient is a substance or organism that has an effect on aquatic organisms and pathogens.

For systems that do not use an active ingredient, the approval process is simple. They only need to perform a land based test, which can be done in a laboratory, and a ship board test. If both these tests show that they are in compliance with IMO's D-2 standards, a final type approval certificate is issued. The type approval is issued by the flag state administration, or often a class society acting on behalf of the flag state administration.

Systems that make use of an active ingredient have to go through a more rigorous approval process. IMO have developed a convention, or separate guidelines for this purpose, popularly referred to as G9. This testing regime both focuses on biological killing efficacy, and the quality of the discharged ballast water. The major difference is that these systems do need a basic approval before they can start testing the systems biological killing efficacy.

A basic approval is issued by MEPC, and is an evaluation of the environmental impact the treated ballast water have when discharged. This is issued on the basis of the GESAMP – BWWG recommendations. Once a basic approval for the active substance is acquired, the efficacy has to be tested. It is important to note, as seen in figure 1 below, that only the environmental impact of the discharged ballast water is evaluated by IMO, while flag state evaluates whether or not the system adheres to the IMO performance standards.

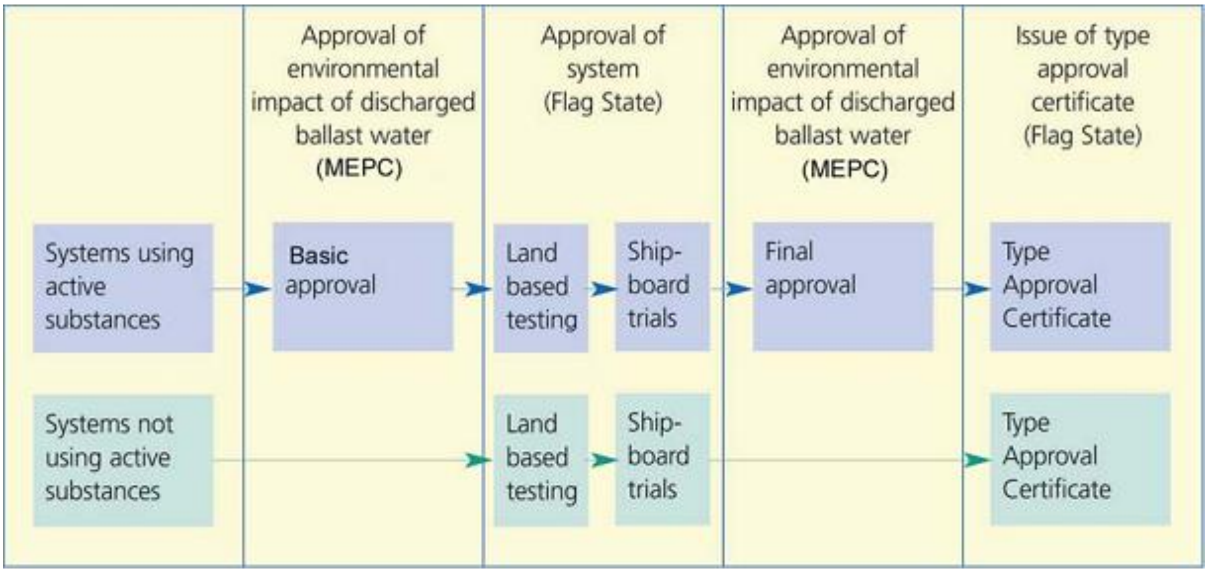

Figure 1: IMO approval process[6]

Currently the final type approval is issued by flag state, and a system approved by one state is not automatically approved by other states. This can pose as a problem when the convention is formally ratified. Ship owners should investigate if the system could be used in all possible ports of calls. Currently, the Norwegian Coastal Administration has outsourced the type approval to DNV and NIVA, and several foreign vendors want approval (or an additional approval) through Norway and DNV due to the international reputation of DNV. This might be a temporary solution, but the best way to facilitate an international approval system is to standardize the performance analysis and evaluation.

2.4 California regulations

This chapter is mostly based on "Assessment of the efficacy, availability and environmental impacts of ballast water treatment systems for use in California water". There are two published versions, one from 2007 [7] and one from 2009 [6].

Kristian Gerhard Jebsen Skipsrederi requested that also the California state laws should be included in this study, since parts of their fleet sail in and around the American continent, and it is likely they will sail in Californian or US waters. Since California have, so far, set the strictest performance standards due to fragile ecosystems, it is reasonable to assume that any treatment system that is in compliance with California performance standard will most likely be in compliance with federal and other state laws in USA.

Organism (size)	California Standard	IMO Standard
> 50 µm	No detectable living organism	< 10 viable organisms per m^3
10 - 50 µm	< 0.01 living organism per ml	< 10 viable organisms per ml
< 10 µm minimum dimension (living)	< 10^3 bacteria/100 ml < 10^4 viruses/100 ml	- -
Escherichia coli	< 126 cfu/100 ml	< 250 cfu/100 ml
Intestinal entercocci	<33 cfu/100 ml	< 100 cfu/100 ml
Toxicogenix Vibrio Cholorae (O1 & O139)	< 1 cfu/ 100 ml or < 1 cfu/gram wet weight zoological samples	<1 cfu/100 ml or < cfu/gram wet weight zooplankton samples

Table 4: California performance standard compared to IMO performance standard [6]

As the table above shows, the California standard is stricter than the IMO standard. Most interesting is the category of living organisms less than 10 µm. As stated in "Assessment of the efficacy, availability and environmental impacts of ballast water treatment systems for use in California waters" there is no technique available to both quantify and assess the viability of bacteria and virus in ballast water. The report continues to describe an approach to assess compliance with the bacterial standard, but gives no method or technique to assess the compliance with the virus standard. This poses a problem for both ship owners and vendors, as it is currently not possible to prove a complete compliance with the standard, or a system that is currently considered to be in compliance could, at a later stage, not be able to show test results that are in compliance with the virus standard. There is little that can be done about this problem, but it should be noted when deciding on a treatment system, and the vendor's position on this issue should be clarified.

California also has adopted the same timeframe for compliance as IMO, which is presented in table 1. This means that the there is an 8 year timeframe for all ships to be in compliance. Priority should be placed on ships with a ballast water capacity between 1500 m^2 and 5000 m^3. The only difference is that California has recognized the fact that currently there are not enough systems available for implementation of the rules within 2009. This means they have adjusted the timeline as shown in the table below.

Built year	Ballast capacity	Standard apply beginning in
2010 or later	All	2010
Before 2010	< 1500 m^3	2016
	1500 - 5000 m^3	2014
	> 5000 m^3	2016

Table 5: California timeline for compliance [6]

2.5 California approval process

California does not have a rigorous approval scheme for treatment systems like IMO have. Instead they only require that the vendor performs test with results metrics comparable to the California standard, and if those metrics are within acceptable limits the system is approved. There is however some problems with the metrics presented in the performance standard.

Especially the one concerning bacteria and virus, as there are currently no commonly accepted method to accurately measure compliance with this standard. According to Dobroski, Takata and Scianny and Falkner:

> California's standards for bacteria and viruses pose a significant challenge, as no widely accepted methods exist to both quantify and assess the viability of all bacteria and viruses in a sample of ballast water discharge. [6]

They go on to describe a method for bacterial assessment, and even if it is debated, it is scientifically supported by many experts. It is however not applicable for virus assessment, and there is not presented any method accepted for this:

> Commission staff believes that there are no acceptable methods for verification of compliance with the total viral standard at this time, and that the Commission should proceed with assessment of technologies for the remaining organism size classes in the standards.[6]

For a ship owner this might prove to be a future problem. When a commonly and scientifically supported method for the viral standard is presented, a currently approved, and maybe installed system might have to be tested again, to prove compliance with this standard. If compliance with California standard is vital for operation, compliance with this standard should be considered during procurement of the system. At this stage, the vendor is responsible for proving compliance with the standard, but once the system is installed, the ship owner is responsible for compliance. It is not known how this situation will be handled, but a worst case scenario would be that each system installed would need to be tested separately, and maybe modified in order to be in compliance. This could be a very costly process, as the owner must prove to be in compliance.

Currently, the state of California does not approve any systems, but only inspects if ships are in compliance. Ship owners hold the responsibility for being in compliance with the performance standard, but vendors do not hold a certificate proving the compliance of the system. This might simplify the process of approving systems, but ship owners must show due diligence when investing in a system; they are responsible for compliance.

When it comes to sampling onboard, it is assumed that a system in compliance with G2 guidelines from IMO would suffice for compliance in California. Currently there is no standardized procedure to assess compliance; it is up to the commission from California State Lands Commission to decide how this is handled.

3 Model input

3.1 Requirements

After discussions with KGJS it was made clear that investment cost will be among the most important decision variables. It was also found that the operational costs are relatively low, and will have a minimal impact on the ships operation. Additionally, the company is interested in standardizing treatment systems based on fleet segments. This means that they want to find the most applicable systems for each part of their fleet, instead of finding the best system for each ship on its own.

During these discussions it was also found that some ships, like general cargo carriers, do not always need the full ballast pump capacity, and it will be interesting to investigate further what impact halving the capacity, by installing only one treatment system for one pump, will have on the time spent deballasting. If this is feasible, they will reduce the investment costs with 50% for this type of ships.

Additional variables, like footprint, power requirement, pressure loss and inlet pressure were also found important, but had to be more closely evaluated for each ship. Finally, any limitations like EX restrictions, California approval status and IMO approval status, and if a sampling system is included were found to be important for some ships, while for others not so important.

3.2 Data

The data used in this study was gathered by KGJS by the ballast water project group, based on a questionnaire prepared in late December. Most of the technical issues are covered in that questionnaire, but barely any of the data can be used to estimate any maintenance cost.

The data available showed that the different systems had very few technical differences, and the major differences relate to power consumption, footprint and treatment method. The data available shows that a pure technical analysis will not suffice when trying to decide on a treatment system, though it is possible to exclude some systems by comparing the system data to the physical requirements of the ship.

The system data is entered into a database created in Excel, and some parameters, like investment cost and footprint are converted into grades. This was done by comparing each capacity against each other, and then changing both price and footprint into a grade from 1 – 6, where 1 is the best grade, and 6 is the worst grade. This was done partly to make the data anonymous, but in the case of footprint it was done in order to give a better representation of the parameter.

It is also clear that a complete technical evaluation of each system will most likely be a waste of time; there are too many unknowns, and barely any operational data are available at this stage. This also poses a significant challenge when it comes to any operational analysis. This means that the only way to really identify the best ballast water system is by applying case studies and identifying areas of concern. After agreement of guidance counsellor at NTNU, Maurice White, it was agreed to only do a simplified LCCA for applicable systems for each case study, instead of creating a generic set to be applied on generic systems, where primary focus will be on installation and investment costs.

3.3 KPI selection

Based on the discussions with KGJS a set of KPI's was generated and had to be assigned an importance (weighed). This was a fairly difficult task, as each ship will present different challenges, and each ship has to be evaluated differently. Additionally, the data set available also contained items that can be considered as either on or off, i.e. satisfy or do not satisfy the requirement. If these were to be evaluated as KPI's, they would either have maximum score or minimum score, depending on whether they were on or off. This prompted that the evaluation had to be differentiated, into a technical evaluation and a KPI evaluation.

KPI	Importance	Description
Power requirement	20%	System required power
Footprint	10%	Comparative grade
Pressure loss	20%	Pressure loss caused by installing treatment system
Required inlet pressure	10%	Minimum required pressure at system inlet
Investment cost	40%	Comparative grade

Table 6: KPI importance

Table 6 above shows the importance of each identified KPI. While there are several other key factors that are important to evaluate when looking at ballast water treatment systems, these are among the few that can be evaluated as a KPI's.

3.4 Technical evaluation

The technical evaluation is significantly simpler, but was more time consuming to create due to the complexity in the formulas needed to separate the different flow rates. Table 7 below shows the additional items evaluated in the technical evaluation.

Item	Importance	Description
Ballast pump capacity	Critical	Flow rate of ballast pump
EX restrictions	Critical, if required	If the system can installed in hazardous areas, where required
Delivery time	Secondary	In months
Sampling system	Secondary	Delivered by vendor
Retention time	Secondary	Minimum time the ballast water has to be retain in tanks for safe discharge without neutralizer

Table 7: Technical evaluation

These are in place to make sure the systems are applicable to the ship, and also use some secondary criteria to further eliminate some systems. This evaluation basically only checks if the systems are within the boundaries set by the users input data.

4 Model

4.1 Technical model

The model is divided into two parts. The first part is a model created in Excel, which evaluates parameters from the ship, and compares it to the data collected from different vendors and evaluates if the system is applicable for each ship. There are other tools available that would most likely be more suited to this task, but Excel was chosen due to the ease of use for the end user. Additionally, Excel is also available for employees at KGJS, where more suited tools might not be.

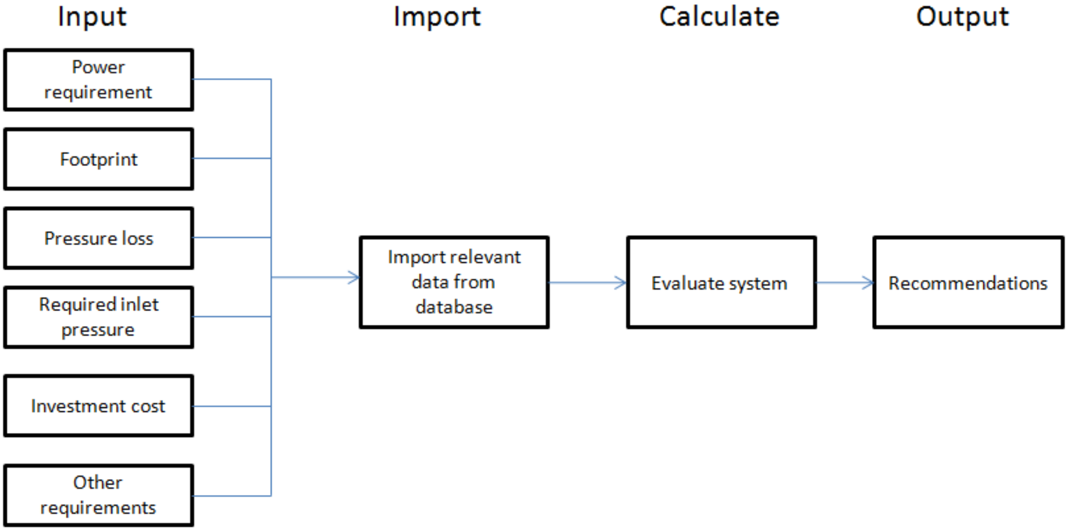

Figure 2: Technical model flow

Figure 2 above shows an overview of how the technical model works. By inserting a few input data, it imports the relevant data from the database, then evaluates if the systems are applicable to the ship and gives a recommendation based on this evaluation. In addition to the technical input, there are some more practical inputs, e.g. if a sampling system is included, IMO approval status etc.

This part of the model is an early screening process automated. It just evaluates quantifiable data, but even if a system is evaluated as applicable by this process, it is not a guarantee that it is actually usable for the ship, as the model uses a fairly simple concept. The first part is a user input, where data from the ship and other requirements are entered. Then the model checks what systems can be delivered for that ships pump capacity, and fetches the data for these systems. This data is then compared to the input data, and the model generates a binary 1x10 matrix, where 1 equals OK / yes and 0 equals not OK / no.

System name	HiBallast
Ballast pump capacity	1
Is EX restriction necessary?	1
Maximum allowed pressure loss	1
Ballast pump inlet pressure	1
Is delivery time of less than 6 months critical?	1
Is typical voyage length for vessel less than 24hrs?	1
Is it critical that vendor supply samply system?	1
Estimated available footprint	0
Available power ballasting	1
Investment cost range	1
System applicable?	**Yes**

Figure 3: Example technical model output

Figure 3 above shows an example output from the technical model. The example shows a system that is evaluated as fully compatible with the input data, even though not all criteria are evaluated as OK. This is because the first 7 criteria are considered to be critical, while the last 3 have a significantly lower importance. As a result, the only way a system will be considered as fully applicable is if all of the critical criteria are evaluated as OK.

This is a weakness in the evaluation process, which is important to note. It is a mathematical approach, where it counts the amount of OK criteria a system has, and if all critical criteria are OK, the model will most likely evaluate the system as a plausible candidate. If more than 2 critical criteria are evaluated as not OK, the model will reject the system as a candidate unless all the non critical criteria are OK. This is a purely speculative approach, but due to limitations in Excel it was found that it was too time consuming to make a more thorough approach to the evaluation process. This also stresses the importance of the KPI evaluation, which can be used as verification when the technical model rejects a system.

This model generally only works on a ship to ship basis, and does not take any fleet considerations into account. The primary goal of KGJS is to decide on a few systems that can be installed on their entire fleet, and preferably having a single system within each segment of their fleet. They use a practical approach, where they decide on testing 4 – 6 systems for 6 months to 1 year, and then use the experiences gathered in this period to decide what systems are applicable within each fleet segment. As this test period has yet to start, it is hard to make any fleet considerations.

When changing footprint and price to grade it was possible to see some trends for a few of the systems. By plotting these into a bar graph, it was identifying the systems that were most applicable to small, medium or large ships.

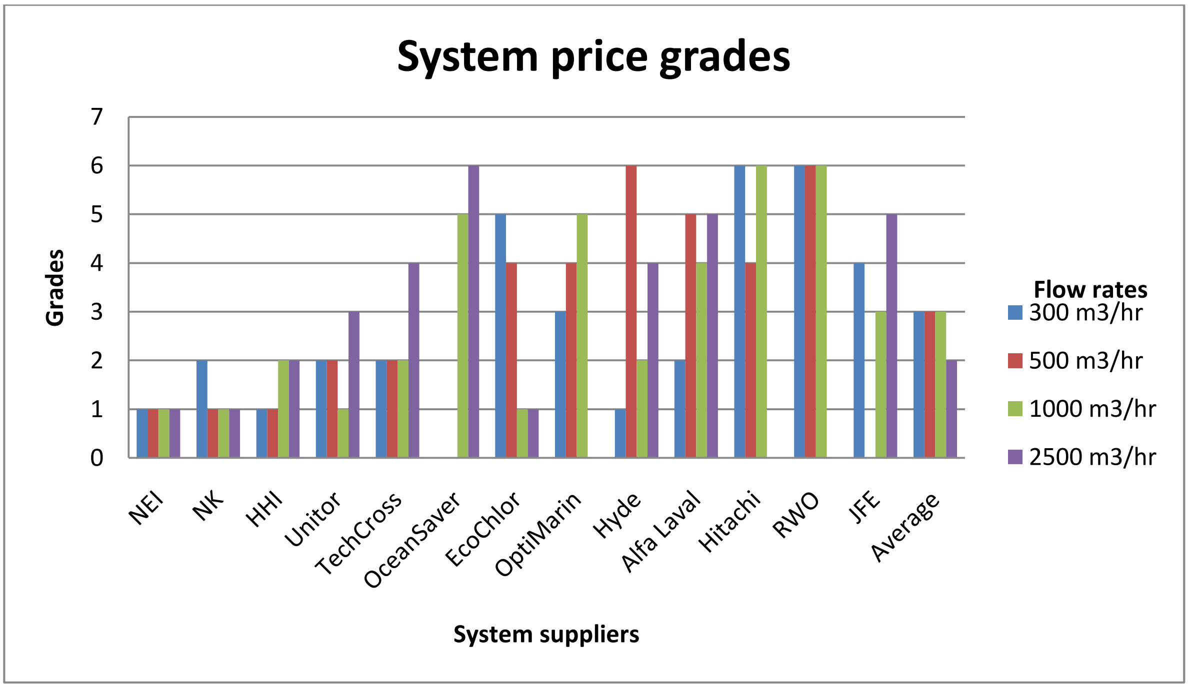

Figure 4: System price grades

As previously said, the grades are from 1- 6, where 1 is the best grade and 6 is the worst. As seen from figure 4, some systems are fairly consistent, while others vary greatly in price for the different capacities. When comparing figure 4 with figure 5 shown below, it is possible to divide the different systems into categories based on capacity.

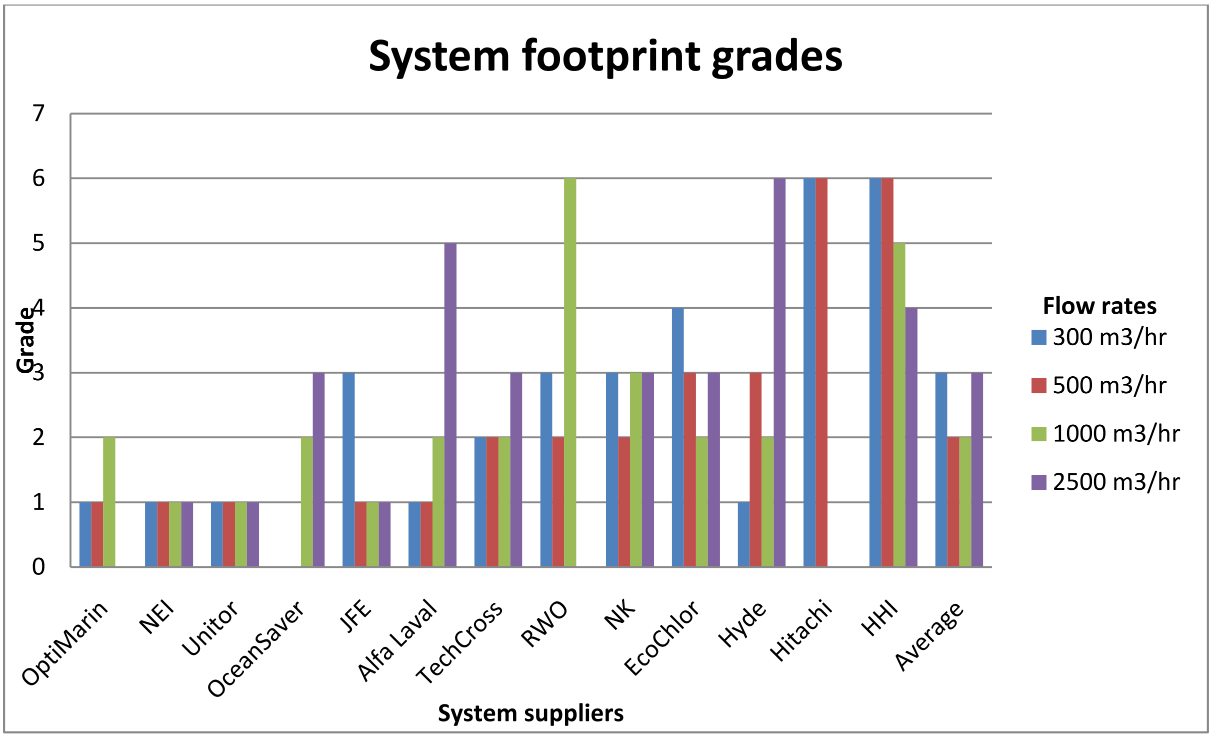

Figure 5: System footprint grades

From these two figures it is possible to conclude that OptiMarin, RWO and Hyde will be most suited for small to medium capacity ballast pumps, while JFE, HHI and EcoChlor will be most suited for larger capacities. The rest are for the most part applicable for all capacities, provided they deliver systems in that range.

4.2 KPI evaluation

Each KPI is graded with a grade from 1 to 6, where 1 is the best grade, and 6 is the worst. This evaluation was done comparatively, where each system was evaluated against the best value (usually the lowest value) within each KPI, using these simple formulae:

(1) $C_{i=\frac{n_i}{n_{min}}}$

(2) $C_{G\,max} = G \times \frac{C_{max}-1}{6} + 1$

(1) calculates the coefficient for each system, where n_i is the actual value of system i, and n_{min} is the smallest (or best) value in the category. (2) calculates the max coefficient for each grade. G is the actual grade, and C_{max} is the highest coefficient in the category. When all coefficients are calculated, the system coefficient is compared to the max coefficient for each grade. It was decided to use grades from 1 to 6, instead of a larger interval, in order to get a better spread in the grades. A larger interval would have caused a smaller difference between each system in some categories.

Additionally it was decided to exclude Hitachi from the footprint coefficient calculations and OceanSaver from the pressure loss coefficient calculations. This was done because these values where so much higher than the other system's that it would have caused a less representative grading for the two KPI's. Instead of calculating the coefficient, they were automatically assigned the worst grade.

The grading calculations is available in appendix 1 (confidential)

Example

For a KPI the systems have the following values:

System	Value
A	400
B	100
C	350

Table 8: Example systems

First step would be to identify the lowest value, in this example it would be system B. The value for system B will then be used as n_{min} in formula (1):

System	Coefficient
A	4
B	1
C	3,5

Table 9: Example systems coefficients

Here, the coefficient for system A would be used as $C_{G\ max}$:

Grade	$C_{G\ max}$
1	1,5
2	2,0
3	2,5
4	3,0
5	3,5
6	4,0

Table 10: Example systems grade coefficients

These grade coefficients are then compared to the system coefficients. For system A, the grade would be 6, as 4 is bigger than 3,5 and equal to 4,0. Finally, for system C the grade would be 5, as 3,5 is larger than 3,0 and equal to 3,5.

This basic method is used on all KPI's, but for KPI's that change over different flow rates each flow rate have been evaluated separately. All the KPI's grades are put back in to the model, and the relevant KPI's are fetched based on the user input. The KPI's are then weighed and the model calculates the average score of all KPI's, which are then presented to the user.

	Power	Footprint	Pressure loss	Inlet pressure	Investment cost	**Score**
OptiMarin	0,60	0,10	0,60	0,30	1,20	**6**
Alfa Laval	0,60	0,10	1,00	0,50	0,80	**6**
OceanSaver	1,20	0,60	1,20	0,60	2,40	**12**
EcoChlor	0,20	0,40	0,60	0,20	2,00	**7**
TechCross	0,20	0,20	0,20	0,30	0,80	**3**
Hyundai	0,20	0,60	0,20	0,10	0,40	**3**
RWO	1,20	0,30	1,00	0,30	2,40	**10**
Hyde	0,20	0,10	1,00	0,40	0,40	**4**
N.E.I.	0,20	0,10	1,20	0,40	0,40	**5**
Unitor	0,20	0,10	1,20	0,50	0,80	**6**
Hitachi	0,40	0,60	0,40	0,10	2,40	**8**
NK	0,60	0,30	0,20	0,60	0,80	**5**
JFE	0,20	0,30	1,00	0,30	1,60	**7**

Figure 6: Example KPI evaluation output

Figure 6 above shows an example output from the KPI evaluation. The systems are listed vertically, while each KPI has its own column. This way it is possible to check each KPI individually for each system and at the same time give an overall grade of the system. The score is the average of the system's grades multiplied by 10. This means that the highest score a system can get is 12, while the lowest possible score is 2. The system also set grades to 6 if the system isn't capable of handling the flow rate, in order to eliminate systems that are not compatible with the ship.

5 User guidelines

The previous chapter focused on explaining the underlying functions of the model, while in this chapter will explain how to use the model, and read the results and identify which systems which are applicable to the ship at hand. It is assumed that the user have a basic knowledge on how to use Excel, so simple operations, like switching between worksheets, are not explained.

The model is basically divided into 6 worksheets, each sheet with a descriptive name. From a user perspective, it is only necessary to look at the worksheets named “Input data”, “Technical evaluation” and “KPI Evaluation” necessary. The other 3 worksheets are the underlying data and various function to import the data relevant to the ship being evaluated.

5.1 Input data

This chapter will focus on the first worksheet, called “Input data”, which is the only worksheet it is necessary to edit in order to use the model.

Figure 7: Input data worksheet selected

This worksheet is the primary input for the model. Here the technical data for the ship is entered, and the other worksheets handle the actual comparisons and evaluations of each system in the database. The figure below shows the layout of the input screen.

Vessel data		
Vessel name		
Vessel age	0	years
Desired footprint range	3	
Minimum available power	208	kW
Is EX proofing necessary?	0	
Ballast pump data		
Ballast pump capacity	300	m^3/hr
Maximum allowed pressure loss	1	bar
Ballast pump inlet pressure	2,5	bar
Economical data		
Investment cost range	4	
Other		
Is California approval required?	1	
Required IMO approval	2	
Desired flag state for IMO approval	8	
Is delivery time of less than 6 months critical?	0	
Is typical voyage length for vessel less than 24hrs?	0	
Is it critical that vendor supply samply system?	1	
Is treatment on inlet only desirable?	1	

Figure 8: Model user input screen

All entries require a numerical input, and a key for most is provided on the worksheet. Table 11 below provide a basic description of each entry.

Item	Description
Vessel name	A means to identify which ship the model consider
Vessel age	Enter age in numbers, but currently do not have any impact on the results (can be ignored)
Desired footprint range	Footprint grade from 1 – 6, key provided on worksheet
Minimum available power	Enter the least available power, in kW, during either loading or unloading
Is EX proofing necessary	Enter 1 if yes, 0 if no
Ballast pump capacity	Enter the ballast pump capacity in m^3/hr
Ballast pump pressure	Enter the ballast pump operating pressure, in bar
Investment cost range	Investment cost grade from 1 – 6, key provided on the worksheet
Is California approval required	Enter 1 for yes, 0 if no
Required IMO approval	Enter the wanted IMO approval from 0 - 3, key provided on the worksheet
Desired flag state for IMO approval	Enter the desired flag state from 1 – 8, key provided on the worksheet
Is delivery time less than 6 months critical	Enter 1 for yes, 0 for no
Is typical voyage length less than 24hrs	Enter 1 for yes, 0 for no
Is it critical that vendor supply sampling system	Enter 1 for yes, 0 for no
Is treatment on inlet only desirable	Enter 1 for yes, 0 for no

Table 11: Input data items

It was decided to use a numerical input system in order to simplify the formulas required to evaluate the system data against the input data. All input keys are provided on the worksheet, except for the yes / no inputs that use a binary system, where 1 means yes and 0 means no. It is important to verify that the data in these fields are correct, as they will help with excluding systems that exists in the database.

For footprint and investment cost, a grade from 1 – 6 have to be entered. The worksheet contains keys, for price it shows the interval for each grade for each flow rate, and for footprint it shows a key based on average grade. A similar system is used for IMO approval and flag state, where the keys are provided on the worksheet.

When all fields are filled in, the model collects the system data, and the KPI grades, for the given flow rate from the database, and evaluate them on the worksheets called “Technical evaluation” and “KPI evaluation”.

It was initially thought to be possible to factor in vessel age into the model. This proved to be a greater challenge than first expected, as for the most part it depends on data not included in the model, as income remaining life time, which has to be compared against investment and installation cost. Most likely this has to be evaluated for each ship individually.

5.2 Technical evaluation

This worksheet will show the results of the technical evaluation of the model. It is important that no cells in this worksheet are edited, as it might break the underlying formulas. The only exception would be if the model is expanded, either by adding criteria or by adding additional systems into the model.

Figure 9: Technical evaluation worksheet selected

The basic layout, as shown in figure 9 below, of the worksheet is that each row is a criterion, while the systems are presented in the columns. The worksheet is divided into 3 blocks, like the one presented in figure 10, each containing 4 systems, and one block containing 1 system.

System name	OptiMarin Ballast System	Pureballast	OceanSaver	Ecochlor BWTS
Ballast pump capacity	1	1	0	1
Is EX proofing necessary?	1	1	0	1
Maximum allowed pressure loss	1	1	0	1
Ballast pump inlet pressure	1	1	0	1
Is delivery time of less than 6 months critical?	1	1	0	1
Is typical voyage length for vessel less than 24hrs?	1	1	1	1
Is it critical that vendor supply samply system?	1	1	0	1
Footprint	1	1	0	0
Minimum available power	1	1	0	1
Investment cost range	1	1	0	0
System applicable?	**Fully applicable**	**Fully applicable**	**Not applicable**	**Partially applicable**

Figure 10: Technical evaluation output block

Each criterion is evaluated by either a 1 or a 0, and has a final evaluation in the "System applicable?" row. As explained in chapter 3.1, each criterion that the system fulfils is evaluated as 1, and the each criterion it fails are evaluated as 0.

The overall evaluation or the "System applicable" row will give a recommendation based on how many critical criteria the system fulfils. It will only be evaluated as applicable if all the critical criteria (i.e. the 7 first criteria) and at least 2 of the non critical criteria are evaluated as OK. This will be displayed as "Fully applicable". If one of the critical criteria or more than one of the non critical criteria is evaluated as not ok the system will be evaluated as a plausible candidate. This will be displayed as "Partially applicable". Any other situation will result in the system being rejected, which will be displayed as "Not applicable".

As mentioned in chapter 4.1, this evaluation will not always be correct, and all systems that are evaluated as not applicable will have to be manually verified by checking which criteria it fails, and evaluate if these deficiencies could be accepted.

More details on how to interpret the output will be provided in chapter 5.4

5.3 KPI evaluation

The final worksheet in the model is called “KPI evaluation”, which is basically a score card for all the systems. Based on the desired flow rate entered in the “Input data” worksheet the KPI scores are collected from the database, weighed, and presented on this worksheet.

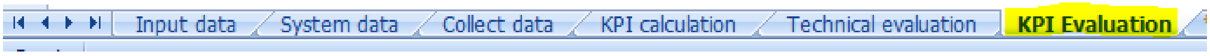

Figure 11: KPI evaluation worksheet selected

This worksheet does not take into account if the system is applicable, nor does it check if the vendor delivers a system for the flow rate set in on the “Input data” worksheet. Instead there is a mechanism in place that makes sure that the system will get the highest possible grade if it is not available for the current flow rate.

	Power	Footprint	Pressure loss	Inlet pressure	Investment cost	**Score**
OptiMarin	0,60	0,10	0,60	0,30	1,20	**6**
Alfa Laval	0,60	0,10	1,00	0,50	0,80	**6**
OceanSaver	1,20	0,60	1,20	0,60	2,40	**12**
EcoChlor	0,20	0,40	0,60	0,20	2,00	**7**
TechCross	0,20	0,20	0,20	0,30	0,80	**3**
Hyundai	0,20	0,60	0,20	0,10	0,40	**3**
RWO	1,20	0,30	1,00	0,30	2,40	**10**
Hyde	0,20	0,10	1,00	0,40	0,40	**4**
N.E.I.	0,20	0,10	1,20	0,40	0,40	**5**
Unitor	0,20	0,10	1,20	0,50	0,80	**6**
Hitachi	0,40	0,60	0,40	0,10	2,40	**8**
NK	0,60	0,30	0,20	0,60	0,80	**5**
JFE	0,20	0,30	1,00	0,30	1,60	**7**

Figure 12: KPI evaluation output

Figure 12 above shows a typical output from the “KPI evaluation” worksheet. One important difference from the output in “Technical evaluation” worksheet is that each system has its own row, while the KPI’s are in columns.

It is also possible to check each KPI’s (Key Performance Indicator) score individually, instead of relying on the overall score only. This can be done to check why a system get a high score and then evaluating whether or not this will exclude the system, or the high score is negligible compared to the benefits. As explained in chapter 4.2, this evaluation use a grade from 1 – 6 imported from the database, and the score is given by multiplying that grade with each KPI’s weight.

KPI	Weight	Min grade	Max grade	Average
Power	20%	0,2	1,2	0,46
Footprint	10%	0,1	0,6	0,29
Pressure loss	20%	0,2	1,2	0,75
Inlet pressure	10%	0,1	0,6	0,35
Investment	40%	0,4	2,4	1,26
Total	100 %	2	12	6

Table 12: KPI weight key

Table 12 above shows the KPI weight input table presented on the worksheet. In this it is possible to change the relative weight of each KPI, and the KPI evaluation is automatically updated. The table also shows the minimum and maximum possible score for each KPI and for the overall score. It also calculates the average grade for each KPI over all the systems.

5.4 Interpreting the output

When interpreting the output pages, it is important to understand the meaning of each value. While this is explained in detail in the previous chapters, I will not go into detail here on each item, but rather give an overview on how to read the output worksheets.

System name	OptiMarin Ballast System	Pureballast	OceanSaver	Ecochlor BWTS
Ballast pump capacity	1	1	0	1
Is EX proofing necessary?	1	1	0	1
Maximum allowed pressure loss	1	1	0	1
Ballast pump inlet pressure	1	1	0	1
Is delivery time of less than 6 months critical?	1	1	0	1
Is typical voyage length for vessel less than 24hrs?	1	1	1	1
Is it critical that vendor supply samply system?	1	1	0	1
Footprint	1	1	0	0
Minimum available power	1	1	0	1
Investment cost range	1	1	0	0
System applicable?	**Fully applicable**	**Fully applicable**	**Not applicable**	**Partially applicable**

Figure 13: Technical evaluation output block

Figure 13 above shows a typical output block from the technical evaluation. The first cell to check is the “System applicable?” cell for each system, in order to get a quick overview. If the system is evaluated as “Not applicable” or “Partially applicable”, make a note of which criteria it fails. From these it is possible to identify the weak points of the system. The same procedure should be followed for each of the systems that are evaluated as fully applicable, as previously mentioned in chapter 5.2 it is possible for system to be evaluated as fully applicable even though it fails to fulfil some of the non critical criteria. From this evaluation, it is possible to extract a list of plausible candidate systems for the ship. Next step would be to cross reference this evaluation with the KPI evaluation.

	Power	Footprint	Pressure loss	Inlet pressure	Investment cost	**Score**
OptiMarin	0,60	0,10	0,60	0,30	1,20	**6**
Alfa Laval	0,60	0,10	1,00	0,50	0,80	**6**
OceanSaver	1,20	0,60	1,20	0,60	2,40	**12**
EcoChlor	0,20	0,40	0,60	0,20	2,00	**7**

Figure 14: KPI evaluation output

Figure 14 above shows an excerpt of the KPI, showing the same systems as figure 13. In the same worksheet a key is provided, showing the minimum and maximum grade possible, as well as the current average grade for each KPI. This key is show in table 13 below.

KPI	Weight	Min grade	Max grade	Average
Power	20%	0,2	1,2	0,46
Footprint	10%	0,1	0,6	0,29
Pressure loss	20%	0,2	1,2	0,75
Inlet pressure	10%	0,1	0,6	0,35
Investment	40%	0,4	2,4	1,26
Total	100 %	2	12	6

Table 13: KPI weight key

Several tests have shown that systems can get similar overall scores, but vary greatly within each KPI. This means that both the overall score and the individual score is important when evaluating systems, however when a system gets an overall score of 9 or higher it will most likely not be a desirable option.

To get a most detailed evaluation, it is important to note how each KPI compares to the minimum and maximum grade, and the average can be used for scores in the mid range. This means it is possible to judge whether a system scores is high, low or near the average for each KPI. Additionally, background knowledge of each system can often be very helpful in the evaluation process.

For example, one of the systems listed in the figures above is EcoChlor BWTS. This system is evaluated as a plausible candidate in the technical evaluation, and gets a total score of just above average in the KPI evaluation. However, what is not included in the model is that the system requires several chemicals to be refilled periodically, and chemical tanks to store these chemicals. In this example, the system would most likely be excluded due to the high investment cost, but it this might not be the case with all similar situations.

When all negative sides of the system is collected from both the technical and KPI evaluation it is possible to further exclude systems, and in the end have a relatively short list remaining. For the systems on this list, it is necessary to continue to case studies in order to identify the most desirable option.

6 Detailed analysis

When applying the model to some example ships, it was found that it was not possible to use it to identify the most desirable option. This prompted a more detailed analysis. It was decided, in collaboration with KGJS, to use two ships as a basis for this analysis. Focus should be one installation cost, as well as operational issues, like maintenance, reliability and investigate the possibility of installing just one system instead of one for each ballast water pump.

Additionally, KGJS is interested in the possibility of installing just one treatment system on selected ships, and thus halving both the pump capacity and investment cost. The reasoning for this is that some ships, like bulk carriers, have ballast pumps dimensioned based on shore based equipment, while most cargoes takes significantly longer to load. This will only work for systems that only treats on intake, or while the ship is unloading the cargo. This means the ship can use both ballast pumps when loading cargo, or discharging ballast water, when it is more likely that the ship will need full ballast pump capacity to keep up with the cargo operation.

6.3 Intention

As explained in chapter 5, the model is not capable of exclusively recommending a single system, but rather excludes systems that are not applicable. In order to further narrow down the options, a more detailed analysis is required. This will include important parameters like installation costs, operational costs and time lost both due to pressure loss and due to halving the pump capacity.

The original intention of this analysis was to perform a simple FTA (Fault Tree Analysis), and a detailed maintenance analysis. However, after discussions with KGJS, who found maintenance cost to be negligible it was decided, by both author and advisor at NTNU, to reduce the scope of this study and rather provide a more detailed installation cost analysis, and a small study into lost time. Also, the lack of any statistical data and experience data for reliability of these types of systems also limited the possible benefit of a more detailed FTA and maintenance cost study.

The installation cost analysis is based on standardized prices from Asian shipyards provided by KGJS.

6.2 Detailed analysis worksheet

The process used in this report is divided into two parts. The first part is to gather the results from the automated model, and evaluate the systems that are applicable to the ship you are evaluating. This also includes gathering the additional information, as described in chapter 5.4.

The second part is a more detailed cost and operational analysis, with emphasis on installation costs. The electronic version of this report contains an Excel workbook that automates much of this process. As very little experience data is available when it comes to installing ballast water treatment systems, it is assumed that the installation will be complete within 7 days for each system. While some are systems are more complex, larger etc, it is assumed some will take longer. However, it assumed that all systems can be installed within 14 days, or a scheduled docking.

OptiMarin Ballast System	Newbuilding Vietnam	
Piping data		
Ballast water pipe diameter	350	mm
Length of piping	8	m
No of bends	4	
No of valves	11	
Steel data		
Assumed steel weight	0,2	ton
Duration		
Expected install time	7	days
Electrical data		
Power requirement	100	kW
Length of cable	20	m
Operational data		
Pump capacity	350	m^3/hr
Ballast tank capacity	3500	m^3
Yearly ballast operations	10	
Pressure loss	0,5	Bar
Inlet pressure	2,5	Bar

Figure 15: Detailed analysis input workbook

Figure 15 above shows an example input for the detailed analysis workbook. As with the decision support model, this workbook is divided into different worksheets.

Worksheet	Purpose
Input	Forms the basis for calculations on the other worksheets
Installation projections	Calculates installation costs
Operational projections	Calculates operational costs
System maintenance database	Intended as support tool for the operational projections worksheets
Lost time	Calculates lost time both due to pressure loss and due to pressure loss and halving pump capacity

Table 14: Worksheets in detailed analysis

As these worksheets all contains detailed instructions on how to use them, and because they are not an absolute, but rather estimations, they will not be explained in detail here.

By updating the input sheet and the inputting the correct prices in Installation projections, an estimate of the costs for the system is provided. As previously mentioned, very little data is available regarding the operational costs, so instead of providing a generic worksheet for calculation the operational costs, a simple analysis with the known values for each system is used instead. The installation cost analysis use standardized prizes from Asian shipyards.

In addition to the installation analysis, KGJS wanted a short analysis of the lost time due to both pressure loss, and due to halving the ballast pump capacity (i.e. only installing one treatment system). For estimating the capacity lost due to pressure loss it is possible to use the “affinity laws”.

The "affinity laws" are normally used to compare the flow-pressure characteristics of a pump operating at different speeds or the effect of changing impeller diameter. The pressure loss equation for turbulent pipe flow:

$$(1)\ P = f \times \rho \times V^2 \times \frac{L}{2 \times D}$$

Where f is the Darcy friction factor as commonly used in the Moody diagram, may be derived by dimensional analysis. This can be simplified to:

$$(2)\ P = k \times Q^2$$

$$(3)\ \frac{P_1}{P_2} = \frac{Q_1^2}{Q_2^2}$$

The only thing that is unknown is the second flow rate (Q_2), which can then be found with:

$$(4)\ Q_2 = \sqrt{\frac{P_2}{P_1} \times Q_1^2}$$

This part is finished in the workbook, though the raw version of the workbook does not have adjustment for actual conditions, and will only calculate lost time when ballast tanks are completely filled.

6.3 Ships

After discussions with Kristian Gerhard Jebsen Skipsrederi AS it was decided that two ships were most practicable as case studies. The first is a 17.000 DWT cement carrier currently being built in Vietnam, while the second one is the 72.000 DWT general cargo carrier MV Corrella Arrow. These two were selected primarily due to the fact that both have drawings available in electronic formats.

Secondly they will also represent a challenge as it might be possible to half the capacity of the ballast system during unloading, which will represent a significant saving on a fleet basis. One interesting analysis is to determine if it is feasible to only install one treatment system that only treat on inflow, as generally dry cargo ships have longer unloading cargo cycles than loading cargo cycles. That way you effectively halve the ballast capacity during unloading, while you can use both pumps when loading. This is also a part why these two ships were selected, as this is not possible for a tanker.

Additionally, the ballast water treatment systems power requirement will generally not be an issue for their dry cargo vessels, as the generators are dimensioned for the bow thruster. This will give a simpler installation cost analysis, as no additional generator will be required. Also, both these ships will be among the first that will require a ballast water treatment system.

The full case studies of both these ships are presented in chapter 7 and chapter 8.

7 Case study: Cement carrier

This ship is currently being built in Vietnam, and will be delivered late 2010. As this ship is only 16.000 DWT, and the total ballast pump capacity is 700 m^3/hr (2 x 350 m^3/hr) it is considered a small ship. Further, there is already reserved space for a ballast water treatment system in the engine room, next to the ballast water pumps.

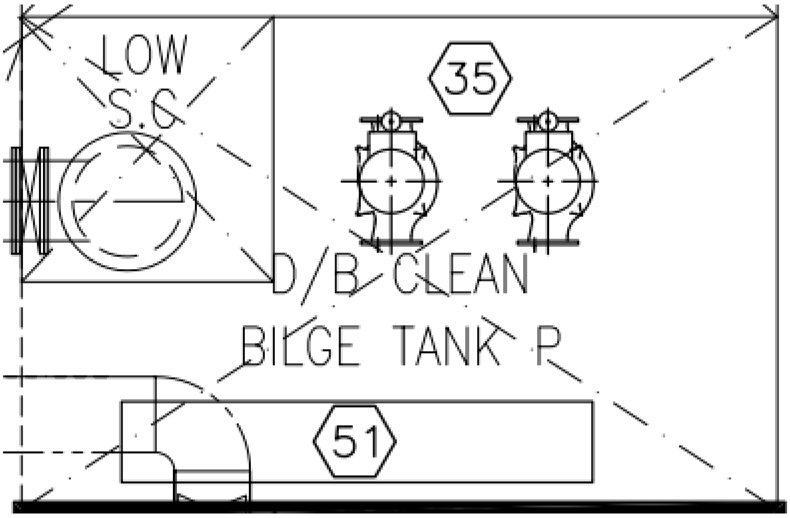

Figure 16: Ballast water pump arrangement cement carrier

The area marked with 51 is reserved space for a ballast water treatment system. It is about 3 meters long and 0,5 meters wide. The height to the ventilation duct on the lower left part is 2,14 meters. This is not absolute, however it is important to make sure the system is accessible for maintenance.

It is important to note that the ship requires a treatment system of 350 m^3/hr, while the model only contains data for 300 m^3/hr systems. This requires another study, where it has to be identified whether the vendor can deliver a 350 m^3/hr system, or if it is necessary to either choke the ballast pumps or invest in a larger system, but in this report it is assumed that the vendor can supply a 350 m^3/hr system.

Minimum available power (defined as either during ballasting or deballasting) is approximately 100 kW, but substantially more can become available by running additional generators. This would be during loading (or deballasting), with 1x538 ekW generator running. This would equal to an 87% load factor, so it is reasonable to assume that an additional generator have to be used during loading.

Output	#	Type
538 ekW	1	Main Generator
1316 ekW	2	Main Generator
250 ekW	1	Harbour / Emergency generator

Table 15: Generators installed on cement carrier

A preferable solution would be to instead of running 1x538 ekW generator, instead use 1x1316 kW generator. This means the total available power would be 850 ekW, and even with an increase of 200 kW the total load factor would be approximately 50%. This means that available power would not be a problem for this ship, but as noted above, it would be necessary to run a larger generator, which at a lower load factor, which might result in a higher fuel consumption.

Alternatively, it is possible to start the harbour / emergency generator, which should be enough for most systems. This means that about 300 kW will be available for a ballast water treatment system. It is not known how much could be saved in terms of fuel savings by optimizing which generators are being used, but it might be worth investigating.

7.1 Model recommendation

By inputting the ship data in the model, and thoroughly examining both the technical and KPI evaluation the following 8 systems were found to be applicable:

System	Comments
OptiMarin Ballast System	Slightly high power requirement
Alfa Laval PureBallast	High pressure loss
TechCross Electro-Cleen	High footprint Inlet pressure must be increased
Wilhelmsen Ships Equipment Unitor	Very high pressure loss Sampling system not included Inlet pressure must be increased
NK-O3 BlueBallast System	Sampling system not included Inlet pressure must be increased
Hyde Guardian	High pressure loss Sampling system not included

Table 16: Applicable systems for cement carrier

As seen in the table above, none of the systems are optimal. Additionally, the Unitor system seems to have more drawbacks than the other systems, but was chosen to be included as treatment is only required on inlet, which makes it possible to install only one system. Table 15, below, shows the systems that the technical evaluation found applicable, but were discarded by cross referencing with the KPI evaluation.

System	Comments
EcoChlor BWTS	Large footprint High investment cost Requires chemicals and chemical tanks
RWO Clean Ballast	High footprint High investment cost High pressure loss High power requirements
JFE BallastAce	Inlet pressure must be increased Sampling system not included High footprint High investment cost Inexperienced company
Hitachi Clear Ballast	High footprint Sampling system not included Complex system Inexperienced company

Table 17: Rejected systems

In addition to these, two systems were discarded as unfit for this vessel. The first, N.E.I. Venturi Oxygen Stripping system, where discarded because it is unsure whether it will be approved by all flag states. During the IMO approval process, the flag state that represent the systems vendor will decide whether the system use an active substance or not. For VOS the flag states, Liberia, Marshal Islands and Malta, decided that VOS did not use an active substance. As the system reduces the pH value of the treated water, it is uncertain whether all states will agree with that decision.

The second system discarded, Hyundai Heavy Industries HiBallast was discarded. This was discarded mostly because the high footprint, but also because they do not have a basic approval from IMO, which means the system will not be permanently approved for some time to come.

There are several other systems included in the model which were rejected directly by the model, with no need for cross referencing the technical evaluation with the KPI evaluation, e.g. the system is not available for the given capacity.

This process shows that even though the model is capable of filtering out some systems, it is hard to single out one system.

The model's output is available in appendix 2 (Technical evaluation) and appendix 3 (KPI evaluation).

7.2 OptiMarin Ballast System

OptiMarin Ballast System is using ultra violet radiation as primary treatment. It uses high pressure UV lamps, which produce UV light at wavelengths ranging from 100 – 700 nano meters, which is within the visible spectrum. High pressure UV lamps also produce less UV light with germicidal properties, and operate at temperatures 500 – 600 degrees Celsius [8].

By exposing the organisms to ultraviolet light, the genetic information contained in DNA are destroyed, and prevents the organism for reproducing. Even though the organisms are not removed from the water, it is not able to settle in a new location [9].The efficacy of ultra violet treatment is dependent on intensity, area and exposure time , and on the grade of turbidity of the water. If there is a high sediment load present, the organisms may not get sufficient exposure, and the treatment will be less effective. [9] [10].

The key benefits with an ultraviolet system are that it is a simple system with no negative effect on ballast water tanks corrosion or coating. Additional benefits of OptiMarin Ballast System are the flexibility of the equipment, as the orientation of the UV reactor does not matter. One uncertainty is that the company is small and has recently been established.

7.2.1 Location

As mentioned earlier, this ship has reserved space for a ballast water treatment system. This means location will not be an issue, but it is important to check if the system fits in the reserved space, or other arrangements have to be made, or if they are at all possible to make.

Optimally, the system will be located close to the ballast water pumps, where other components, like starter panels and cabinets may be located as close as space permits (e.g. on deck above or on a gallery beside the unit). This will among other things reduce the installation cost, and also make the piping arrangement easier.

Figure 17: OptiMarin Ballast System

The figure above shows a typical layout of a 334 m^3/hr OptiMarin Ballast System. 1 is the MicroKill UV reactors, 2 is the MicroKill filter and 3 and 4 are the control system, where 4 is most likely the local control panel and 3 is the remote control panel. It was not found the exact dimensions for the treatment system, but from the database, individual components footprint is available. This means it is possible to extrapolate some approximate dimensions.

Component	Footprint	LXB
MicroKill UV reactor	1,8 m^2	4x0,45 meters
MicroKill Filter	0,76 m^2	Radius: 0,5 meters
UV Power supply unit	1,8 m^2	4x0,45 meters

Table 18: OptiMarin estimated dimensions

From the database, only the exact dimensions of the UV power supply unit were available, and it was assumed that the UV reactor has the same dimensions. Max height available is 2,14 meters, while the figure above shows that the man is higher than the treatment system, and thus this will not be a problem. The dimensions for the control units are not included, as they are very flexible in terms of installation location.

Figure 18: OptiMarin Installed on MV KCL Banshee

The figure above shows the system installed on MV KCL Banshee, a 5.000 DWT cement carrier owned by the Thorvald Klaveness Group. When comparing figure 16 to figure 17, it shows clearly how flexible OptiMarin is regarding equipment arrangement. In figure 16 the UV reactors are mounted directly on the filter, while in figure 17 the UV reactors and filters are installed at some distance from each other. Figure 17 also show the local control panels are mounted directly above the UV reactors, while figure 16 does not really show any point of reference around the control panels.

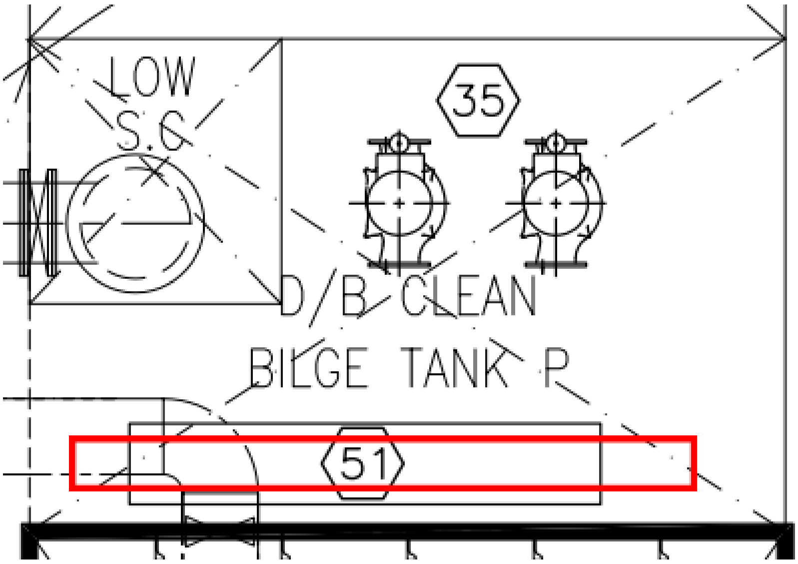

Figure 19: OptiMarin estimated area

For this ship, the available space is about 3 meters long and 0,5 meters wide. Figure 18 above shows the estimated space this system will occupy. As seen on figure 19, it will exceed the reserved space, however the space between the fore bulkhead (right most on the figure) is approximately 0,5 meters, which will provide access for maintenance. It will be located approximately 1,3 meters from the ballast pumps. Also note that the reserved width in figure 18 is approximately 0,45 meters, while the filter have an approximate width of 1 meter. While that might be a cause for concern if the filter is located at the aft part (left most on the figure) of the reserved area, it will not be a problem if it is located at fore part.

As mentioned earlier, the control panels are relatively flexible when it comes to location. It is reasonable to assume that the local control panel can be mounted at a bulkhead, or directly on one of the treatment units. As figure 18 shows, both the foremost bulkhead and the port bulkhead. For the remote control panels, it is reasonable to assume that it will not be possible to install them close to the ballast pumps, but when looking at the full engine room arrangement drawing, presented in appendix 4, it would most likely be possible to place them just fore of the main engine on the tank top deck. This would be approximately 8 meters from the ballast pumps. This shows that it is fully possible to install OptiMarin Ballast System on this ship. It is not known whether there are any limitations for the location of the remote control panel. If it is possible, it might be desirable to install these in the engine control room or similar.

All figures in this chapter are collected from the OptiMarin website, with the exception of figure 19.

7.2.2 Installation costs

Internal studies in KGJS have shown that installation cost combined with investment cost will be the most important factors when deciding on a ballast water treatment system. In this study, it is assumed that the system can be installed during a scheduled docking, so no docking fees or similar is included.

For OptiMarin, the estimated installation cost is $180 000, where the majority would be used on the electrical system. Table X below shows the detailed costs. As previously mentioned, the installation costs are based on standardized prices from Asian shipyards, and it is assumed that the system can be installed during a scheduled docking.

Piping cost	
Pipes	$2 048
Bends	$716
Valves	$38 500
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$467
Switchboard work	$5 667
Switch	$11 958
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$177 555

Table 19: OptiMarin installation costs

7.2.3 Operational costs

For OptiMarin, there was little information available in terms of operational costs. Most operational estimations in this report is based on numbers from Lloyd's Register "Ballast water treatment technology: Current stats" (2007) [11]. For some reason, OptiMarin does not have any operational costs covered in this report. However, after discussions with KGJS, it was found that maintenance would mostly be replacing the UV lamps. These have an estimated lifetime of 1000 hrs in operation. This ship will most likely fill the ballast tanks about 90% each ballast operation. With a total ballast capacity of 5 000 m^3, this would equal to one maintenance operation after approximately 155 ballast operations. With assumed 25 ballast operations yearly, this would equal to one maintenance intervention after approximately 6 years.

This shows an insignificant maintenance cost, but might be a bit misleading, as it fails to include the filter and its associated maintenance operations. But even when including the filter, it is assumed that both time and cost related to maintenance will be negligible when comparing it to the installation and investment costs.

In addition to maintenance, installing OptiMarin Ballast System will result in 3,6 tons annual increase of the fuel consumption.

7.2.4 Reliability

For reliability, even less data was available, and no significant experience data is available, as most systems are recently developed and few are in operation. As mentioned earlier, this part of the report will be having a reduced scope. According to the description from OptiMarin, the system has several sensors installed to let the operator know that the system is working as expected.

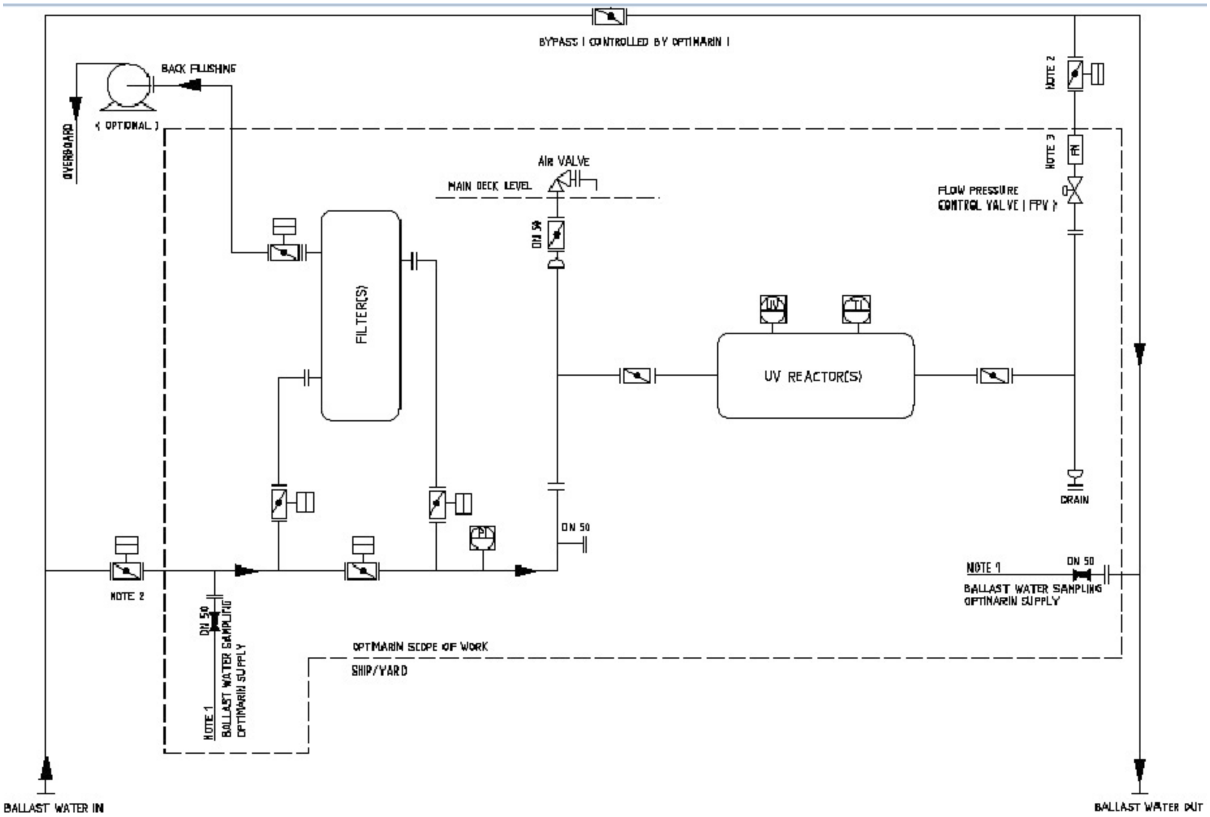

Figure 20: OptiMarin Ballast System flow diagram [12]

From this it is assumed that worst possible scenario is a malfunctioning system which reports that everything is working as expected. This means the operator will not get any warning, and it is likely that during the next deballasting operation untreated water will be discharged. This will result in both down time for the vessel, as it is essentially not capable of ballasting or deballasting, and a probability of a fine if the port authority takes a sample while the system is malfunctioning.

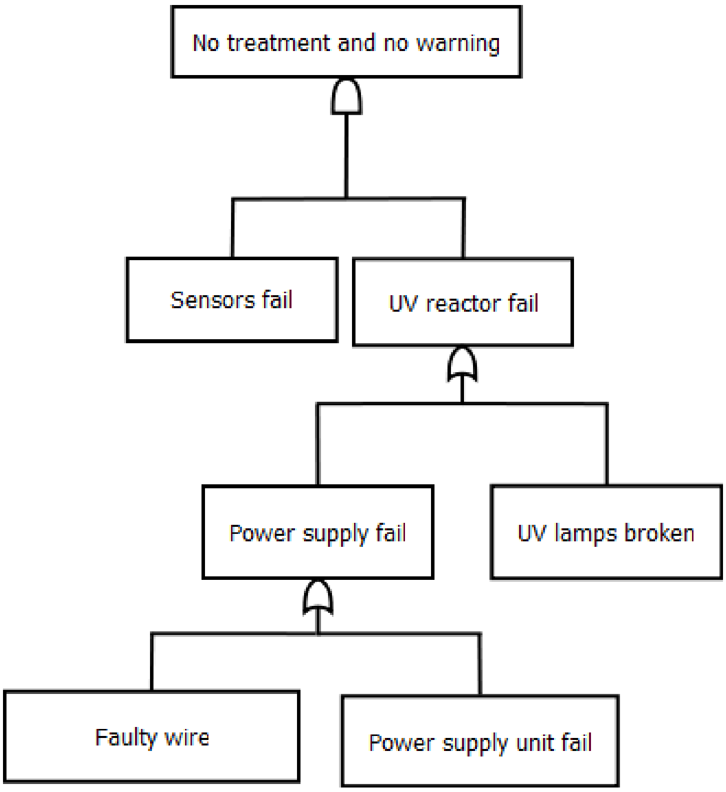

Figure 21: OptiMarin Ballast System Fault Tree

Figure 21 above shows the fault tree for the described scenario. As there is no probability involved, it is hard to make any specific recommendations or conclusions from it. However, experience shows that sensors often are a weak link in systems such as this. It is also assumed that both the power supply unit and connecting wires are of high quality and well protected, the obvious conclusion would be that the weakest part is the sensors. However, both the UV reactor and the sensors have to fail for this scenario to happen.

Not much experience data is available for UV lamps in shipboard systems, especially when considering that the water quality will be very variable. However, it is assumed that experiences from fresh water treatment will be applicable, as seasonable changes in water quality will occur. This further supports the conclusions that the sensors will be the most likely component to fail in this system.

7.2.5 Lost time

For OptiMarin, the pressure loss is given as 0,5 Bar, while the inlet pressure for the ballast pumps is 2,5 Bar. This results in a lost time of 1 hour using both pumps for a full tank. By halving the capacity the lost time would be approximately 9 hours.

As mentioned earlier, this ship will most likely fill the ballast tanks to approximately 90% each time. By adjusting for this, the lost time when halving the capacity will be approximately 8 hours, while for full capacity the lost time will stay approximately the same. As previously mentioned, the decision to halve the capacity is mostly a commercial decision; the lost time will be significant.

However, for OptiMarin it will not be possible to halve the capacity, as it requires treatment both on outlet and inlet.

7.3 Alfa Laval PureBallast

As with OptiMarin Ballast System, Alfa Laval Pureballast is a UV treatment system. As opposed to OptiMarin, PureBallast uses high pressure UV lamps, which basically means that the wave length of the UV output is between 254 nano meters to 264 nano meters. Low pressure lamps are usually considered to the most effective lamps, as more of the input is converted to usable UV-C watts [8].

Unlike OptiMarin, PureBallast requires that the UV lamps are washed after each operation. This adds another 15 minutes for each ballast operation, but this will not affect time in port, as this can be done while the ship is leaving port.

7.3.1 Location

As mentioned earlier, and shown in figure 16, this ship already has a reserved area for ballast water treatment system. This is approximately 3 meters long and 0,5 meters wide.

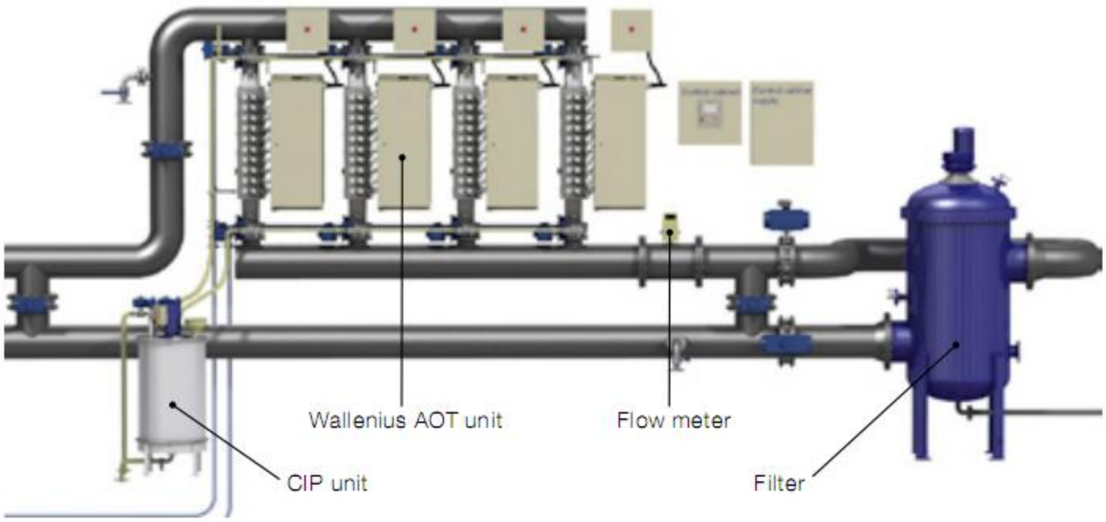

Figure 22: Alfa Laval PureBallast Overview

Figure 22 above shows the general layout of a 1000 m^3/hr treatment system. As seen, the UV unit, or Wallenius AOT unit will be the largest component in the system, while the control panel, which is not marked on the figure, but are located just right of the AOT unit, are mounted on a bulkhead. It is assumed that these are very flexible, as with OptiMarin.

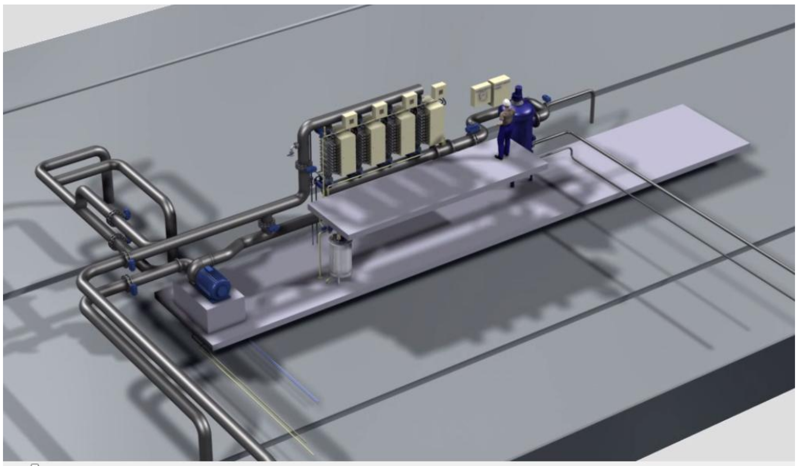

Figure 23: 3D model of PureBallast with piping

Figure 23 above shows the full piping arrangement of an installed PureBallast treatment system. This figure is quite extensive, but shows the dimensions of the system. What is hard to see is the height of the system. The operator on the figure, just in front of the control panel at the right hand side of the system, is actually lower than the maximum height for the system. According to the technical brochure from Alfa Laval, the dimensions for a 250 m^3/hr system are 2m x 0,8m x 1m (length x width x length). Unfortunately, Alfa Laval does not offer any treatment system dimensioned for 350 m^3/hr flow rate. This means you either have to choke the flow rate by installing a smaller system, or increase the investment cost by installing a larger system. This report will assume that the flow rate is choked, as this requires additional technical considerations.

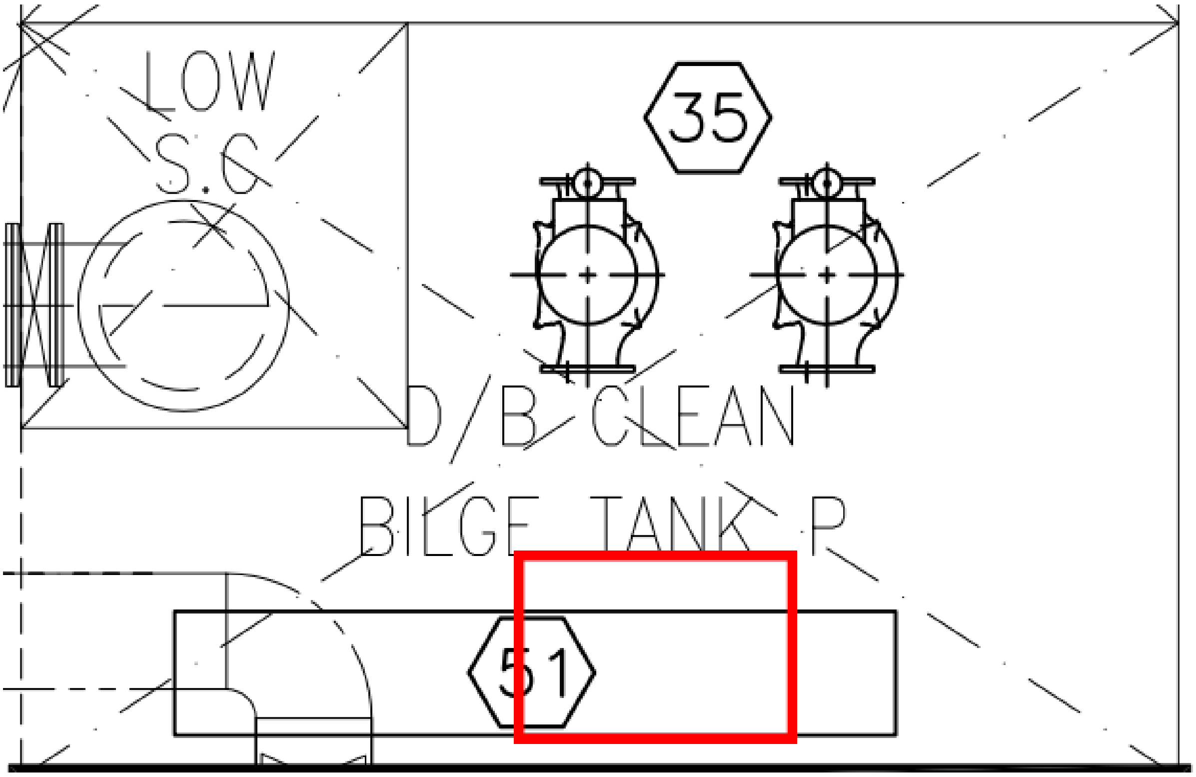

Figure 24: PureBallast estimated area

Figure 24 above shows the estimated area of an installed 250 m^3/hr PureBallast treatment system. The distance between the ballast pumps and treatment unit is approximately 800 mm, which should provide sufficient access for maintenance. As mentioned, the maximum height allowed is 2,14 meters, which is restricted by the ventilation shaft at the lower left part of figure 24. PureBallast have a maximum height of 2 meters, which should not be a problem. This shows that the physical dimensions of PureBallast should not be a problem for this ship.

All figures in this chapter, with the exception of figure 24, are collected from the Alfa Laval website.

7.3.2 Installation costs

Unfortunately, there was no P&ID available for PureBallast, as it were with OptiMarin. This means that some values are very uncertain, especially when it comes to number of valves required. By looking at figure 23 and other 3D models available from the Alfa Laval website, it was possible to count between 9-10 valves.

When it comes to piping, the length required would be approximately the same as for OptiMarin. This resulted in a very similar cost, at approximately $180.000, as OptiMarin. This was expected, as the systems are installed on the approximately same place and have the same power requirement.

Piping cost	
Pipes	$2 048
Bends	$716
Valves	$35 000
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$467
Switchboard work	$5 667
Switch	$11 958
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$174 055

Table 20: PureBallast installation costs

7.3.3 Operational costs

For operational cost there are not much available for PureBallast. However, approximately the same principle as applied for OptiMarin will be valid for PureBallast as well. The major difference would be the lifetime of the UV lamps, which is considerably larger for PureBallast. They are estimated to be approximately 1.500 hours in operation, depending on how many times they are turned on and off. With the assumption that the ship will have 25 ballast operations per year, each at 90% of total ballast capacity, it will be necessary to change the UV lamps after approximately 233 ballast operations, or after 9 years.

This assumption is very simplified, as the filter and the cleaning unit (CIP) will most likely require maintenance as well. However, it shows that the cost will most likely be negligible when compared to installation and investment costs.

In addition to the maintenance costs, PureBallast will cause a yearly increase in fuel consumption with 5,11 tons. The major reason for the difference between PureBallast and OptiMarin, as they have the same power requirement, is because of the assumption that PureBallast will choke the ballast pumps with 100 m^3/hr.

7.3.4 Reliability

The standard assumption is that the worst case scenario is that the treatment unit is malfunctioning, but the operators receive no indication of the malfunction. As previously stated, this will most likely lead to both down time in order to repair the system and most likely a fine if the port authorities discover that the discharged ballast water was not treated according to the regulations.

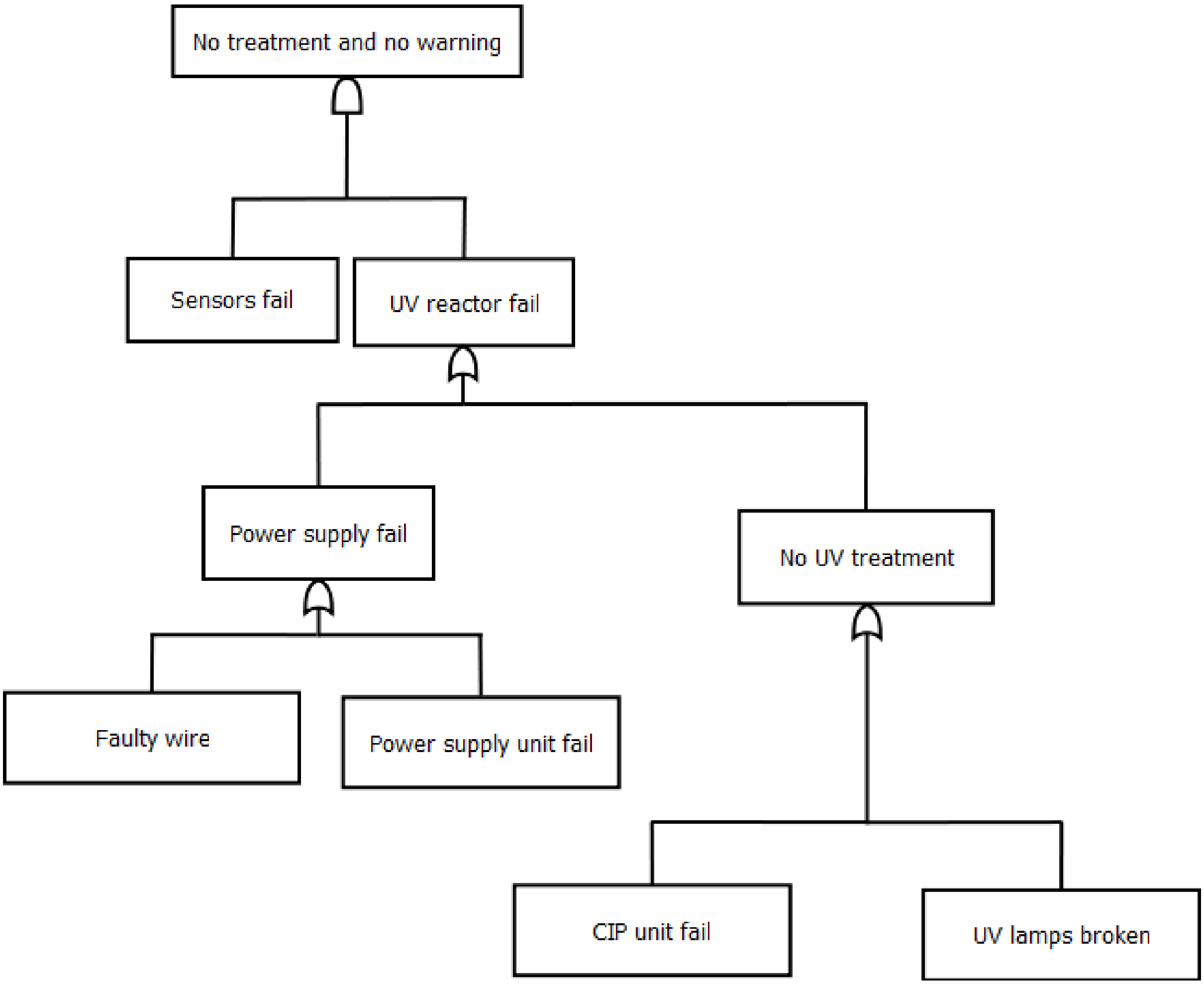

Figure 25: Alfa Laval PureBallast fault tree

Figure 25 above shows the fault tree for this scenario. The main difference between this and OptiMarin, is that due to the fact that PureBallast requires a cleaning unit, there is a possibility that the treatment will not achieve required efficacy as the UV lamps are not properly cleaned after each operation.

It is assumed that both the UV lamps, CIP unit and power supply are all of high quality, it is assumed that the sensors are the weakest link in this fault tree. However, the fault tree clearly shows that both the sensors and UV reactor have to fail, which means this scenario is fairly unlikely.

7.3.5 Lost time

As Alfa Laval requires treatment on both inlet and outlet, halving the capacity will not be possible. But as mentioned in chapter 7.1.3.1, it is assumed that the system will choke the capacity with 100 m^3/hr. This means that the ship will significantly increase time spent pumping in and out ballast water.

This means that the actual ballast pump capacity of the ship will be 2 x 220 m^3/hr. This means the capacity is reduced with 130 m^3/hr, which is quite significant when converting to hours lost. As previously, it is assumed that the ballast tanks will be filled with 90% of total capacity each operation, which results in 4 hours lost time compared to original capacity. This shows that it will most likely be desirable to purchase 2 x 500 m^3/hr systems, at an increased investment cost.

7.4 TechCross Electro-Cleen

Electro-Cleen is an electrolysis system, using hypochlorite as active substance. By applying a mild current to the seawater, the treatment system will produce hypochlorite in line, which an effective germicide. Electro-Cleen requires the ballast water to be treated both on inlet and neutralized on outlet if the TRO (Total Residual Oxidants) exceeds IMO standards.

Among the negative side effects is the possibility for corrosion. According to Song, Dang, Chi and Guan chlorinated seawater will increase corrosion rate 1.3 - .1.7 times compared to that of natural seawater [13]. However, it is not known how coated ballast tanks will be affected by electro chlorinated seawater.

7.4.1 Location

The approximate dimension for Electro-Cleen ECS-300 is about 2m x 1m x 1,8m (Length x Width X Height), and the reserved space is about 3 meters long and 0,5 meters wide, with a minimum height of 2,14 meters. As previous investigations shown, the width is not absolute, and can be exceeded as long as there is sufficient space between ballast pumps and treatment system for maintenance.

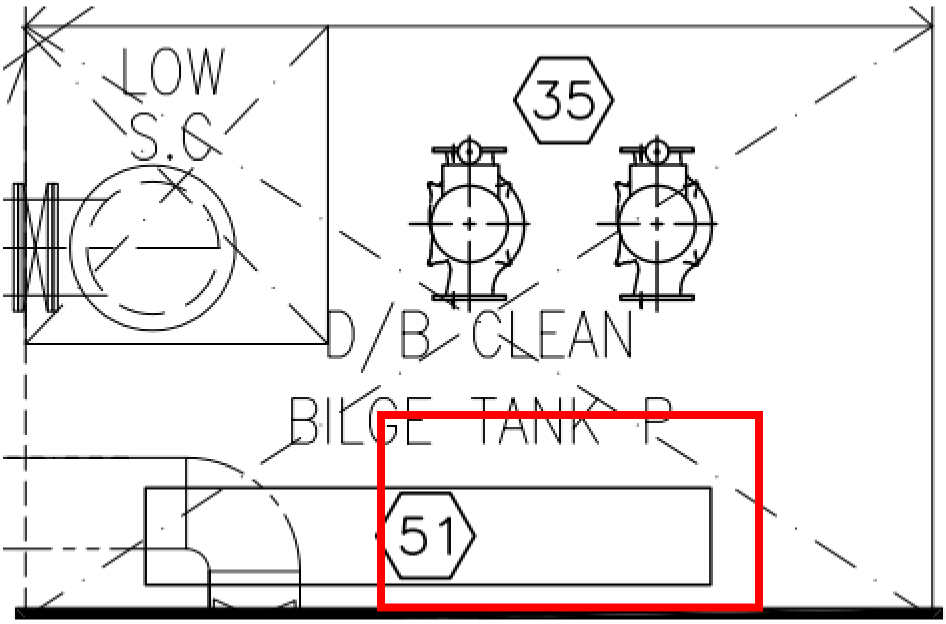

Figure 26: Electro-Cleen estimated area

Figure 26 above shows the approximate area Electro-Cleen will occupy. The distance between the treatment unit and the ballast pumps are just below 0,5 meter, which might be a bit short for proper access.

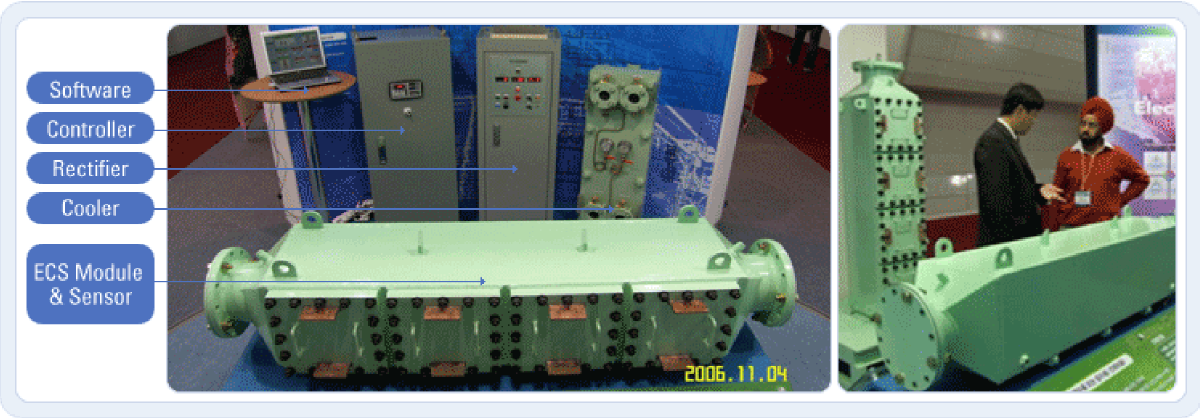

Figure 27: Electro-Cleen system [14]

The figure above shows the layout of the system. The largest module, at the bottom, is the treatment module. This is the only module that needs to be in line with the ballast water piping. According to the dimensions supplied at the TechCross website, the maximum width of this module will be just over 500 mm, or 0,5 meters.

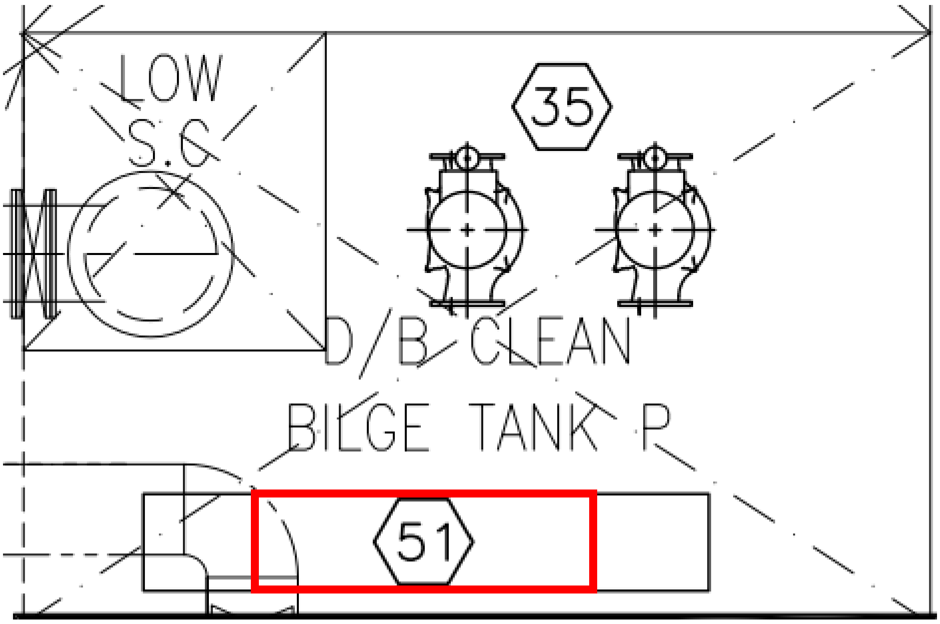

Figure 28: Electro-Cleen ECS module area

Figure 28 shows the adjusted area for only the ECS, or electrolysis module. This will leave enough room for access between the treatment system and ballast pumps. As for the location of the cooler, it is assumed this is mounted on the ECS module, which will most likely only change the height of the module, and not the maximum width. The controller and rectifier will most likely fit on mounted against the foremost bulkhead (to the right on the figure), but the exact dimensions of these are not known.

This shows that there will not be any limitations in terms of area when installing Electro-Cleen.

7.4.2 Installation costs

One of the major advantages of TechCross Electro-Cleen is the simple system, as it does only use one electrolysis module and no filters. This will result in a reduced installation cost, and less time required for installation. As previously mentioned, very little experience data is available for installing a ballast water treatment system, in this report it is assumed that it will take approximately 7 days.

The total estimated installation cost for Electro-Cleen will then be $150.000. The primary reason for Electro-Cleen is cheaper to install than OptiMarin and Alfa Laval is the significantly lower power requirement.

Piping cost	
Pipes	$2 048
Bends	$716
Valves	$21 000
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$467
Switchboard work	$5 000
Switch	$0
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$147 431

Table 21: Electro-Cleen installation costs

7.1.4.3 Operational costs

For Electro-Cleen, it was possible to do some more thorough calculations for maintenance costs. Mostly because they included a detailed list of spares and the approximate interval they would need exchanging. From this list the shortest maintenance interval would be after each use. However, this is for a portable TRO (Total Residual Oxidant) sensor, which would most likely not be used after each ballast operation.

What would be the most challenging are the chemicals required for operation. These are for the neutralizer system, and will be consumed when needed. According to TechCross, this would need to be refilled once a month and the supply will last 12 months. This would equal to a cost of approximately $60 dollars after one year, or $100 if the stored chemicals for the portable TRO sensors are depleted as well. A total approximation would be a total of $200 per year, using the list supplied from TechCross as a reference.

However, during a meeting between KGJS and TechCross it was discovered that the system have to be totally dismantled once each 6 months. While this might be acceptable for smaller systems, like this one, where this can be completed within one day, it will still be a significant strain on the engine room crew.

In addition, Electro-Cleen will increase the yearly fuel consumption with approximately 0,6 tons. This shows that both fuel consumption and maintenance cost will be minimal, while the increased strain on the engine room crew due to the fact that the system has to be dismantled each 6 months will be the decisive factor.

7.4.4 Reliability

The primary advantage of Electro-Cleen is the simplicity of the system. It only consist of one treatment unit, and a few control units, like neutralization unit, control unit etc.

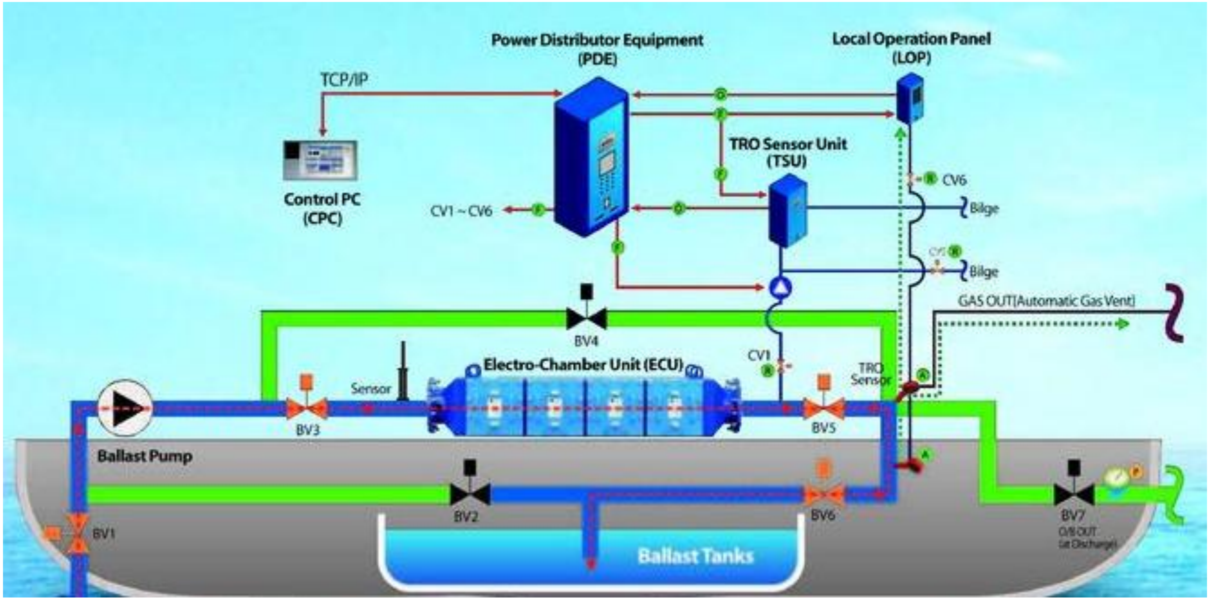

Figure 29: Electro-Cleen flow diagram [15]

The fault tree reflects this, and shows that with few components there are fewer things that can go wrong. As previously mentioned, it is assumed that the worst case scenario is a faulty treatment system with no warning.

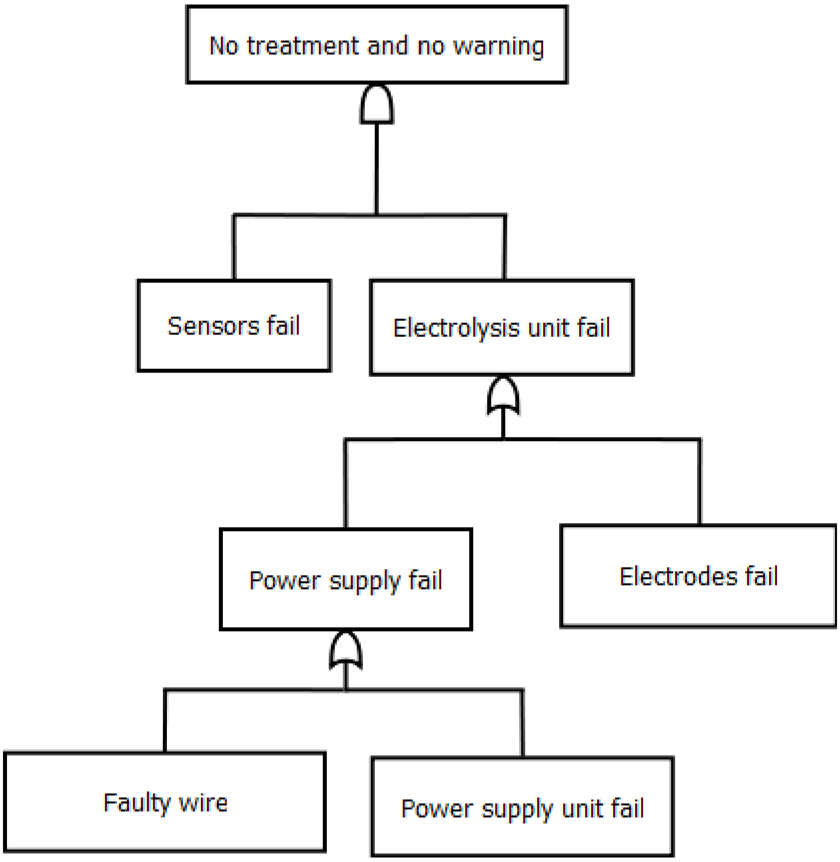

Figure 30: Electro-Cleen fault tree

As seen from figure 30 above, the fault tree is fairly small, due to the simplicity of the system. As there are no experience data available, it is hard to make any guess on which component is most likely to fail. However, as assumed earlier, it is thought to be the sensors that will be the most likely to fail, while both power supply and electrodes are of high quality. In addition, the system will be completely dismantled every 6 months, during this it is likely that any fault in the system will be found.

7.4.5 Lost time

Even though Electro-Cleen are running during both discharge and loading of ballast water, only the neutralizing unit will be running during the discharge operation. As seen from figure 31 below, the TRO will be measured just after the ballast tanks, and the neutralizing agent will be added just after the ballast pumps.

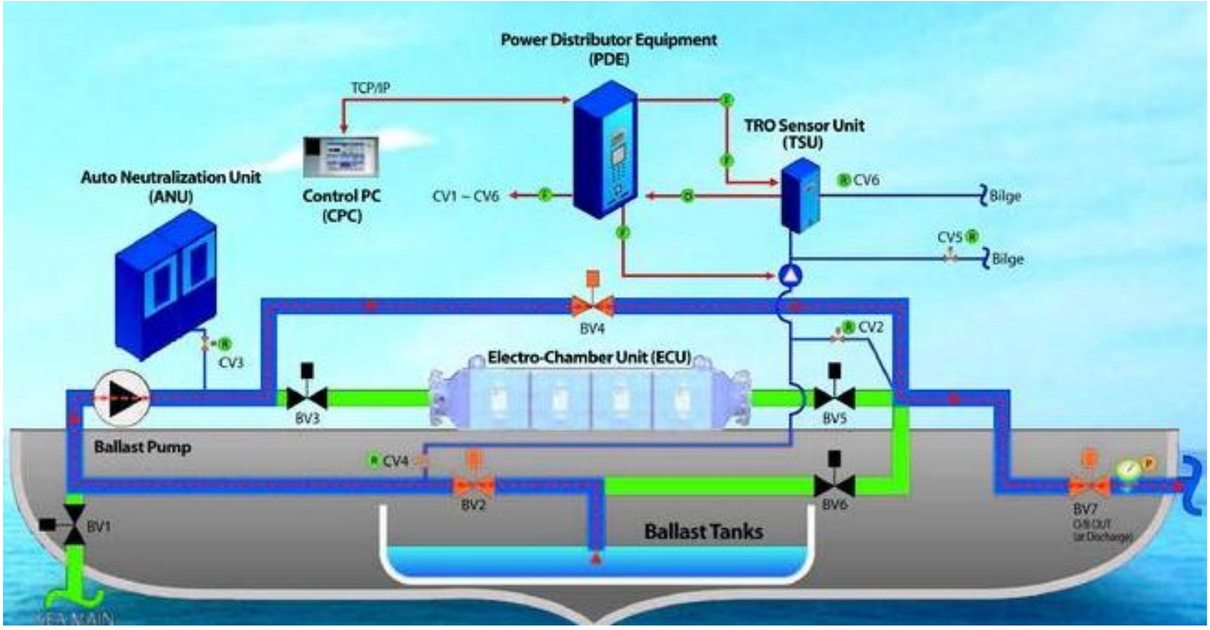

Figure 31: Electro-Cleen flow diagram during discharging [15]

In figure 32 below, an excerpt of the P&ID for the ships ballast system is presented. As seen, this ship uses a ring system, which basically means that the ballast pumps can independently fill starboard or port side ballast tanks.

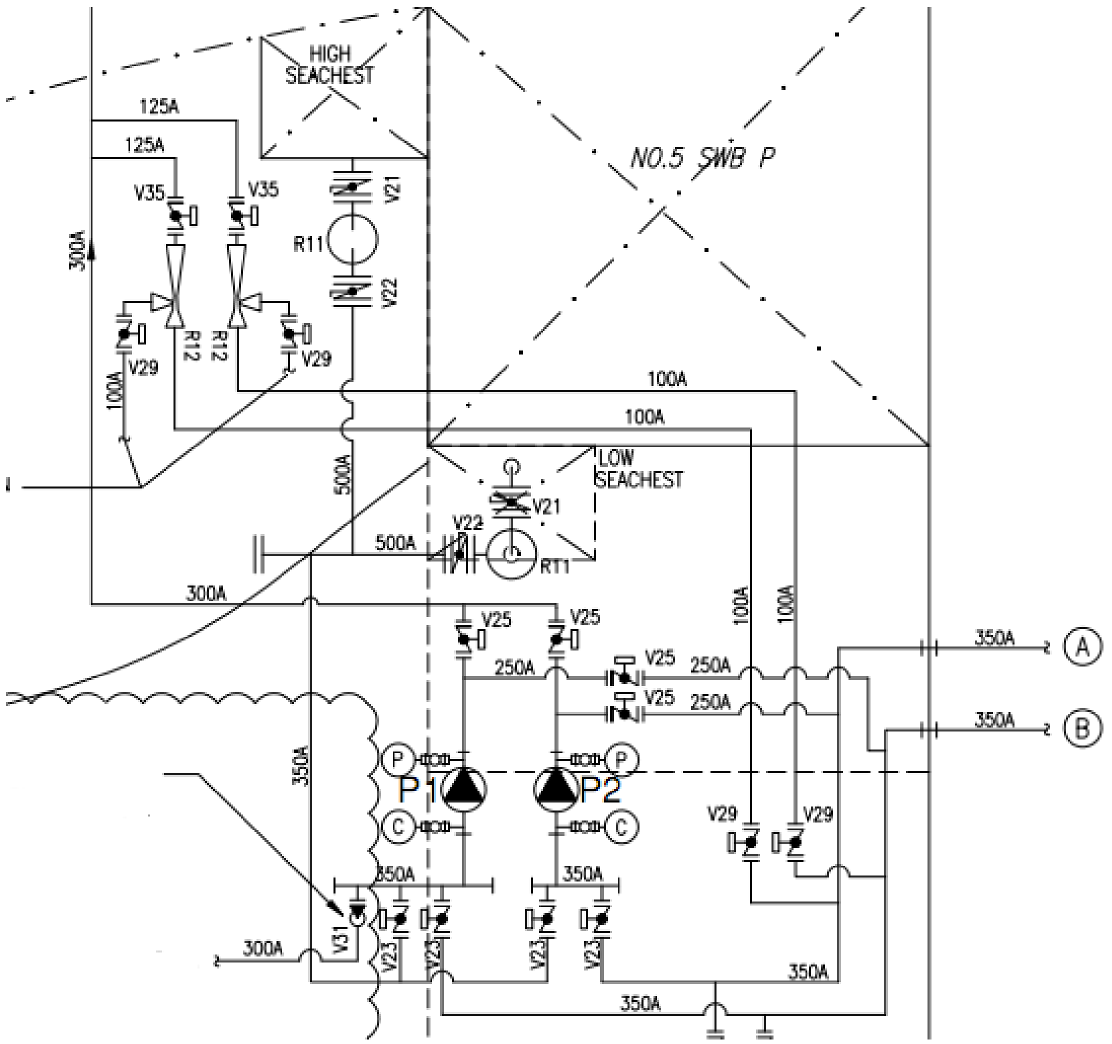

Figure 32: P&ID of cement carrier ballast system

This basically means that during discharge, the pumps will either be assigned port side ballast tanks or starboard side ballast tanks. While this will complicate using only one treatment system, it will not make it impossible. But it is important to note that doing so will increase the cost of engineering and design, as well as the installation costs.

However, the actual time lost by halving the capacity of the ballast pumps is approximately 7 hours, when assuming that the ballast tanks are filled to 90% of total capacity each operation. In comparison, the time lost due to pressure loss (using 2 systems) is approximately 10 minutes. This shows that the time lost due to pressure loss is negligible.

7.5 Wilhelmsen Ships Equipment Unitor

WSE Unitor consists of 4 treatment units, while most systems only have 2 or 3 treatment units. While adding components will increase the complexity of the system, in this case it will reduce the max power requirement for the system. As the system is primarily based on electro chlorination, a process which is dependent on the salinity in the water; low salinity will equal high power consumption.

Treatment	Description
Mechanic filtering	Removing large organisms from ballast water
Electro chlorination	Producing sodium hypochlorite, in salt water
Ozone generator	For assisting the electro chlorination in brackish or fresh water
Cavitation	A pre treatment before exposing the organisms to an active substance

Table 22: WSE Unitor treatment units

The main benefits from using WSE Unitor are the small footprint, low power requirement and only one way treatment (only on intake). However, all treatment are performed before the ballast pumps, meaning that there is a risk of damage to the ballast pumps due to either corrosion or cavitation in the pump. While WSE claims this will not be a problem, it should be noted, and in case of ballast pump breakdown, the impeller and similar should be checked for corrosion and cavitation damages.

While the reactor chambers are located before the ballast pumps, filters will be located after the ballast pump.

7.5.1 Location

As mentioned above, this system consists of several units, but very few have to be installed in line with the ballast water piping.

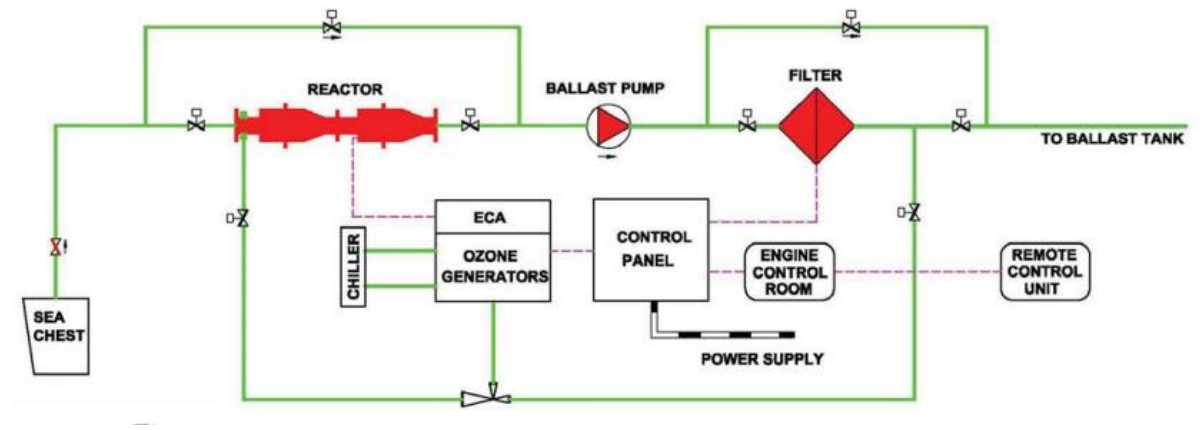

Figure 33: WSE Unitor flow diagram [16]

Figure 33 above shows a generic flow diagram for WSE Unitor. This shows that the reactor unit needs to be placed before the ballast pumps and the filter are located after the ballast pumps. This might pose as a challenge when installing the system. However, for this ship, it is assumed that the system can be installed in the reserved area, with some adjustments to pipe length and similar.

A further assumption is that only the reactor and filter have to be installed close to the ballast pumps, while the control panels can be fitted on a bulkhead. This means the Ozone generators and related equipment can be placed outside this space, depending on what is best suited.

This means that the system will require 3,2 meter length and 0,845 meters width for the reactor unit, and the filter will have a 0,937 meter diameter. This will result in a max length of 4,1 meters and a max width of 0,937 meters.

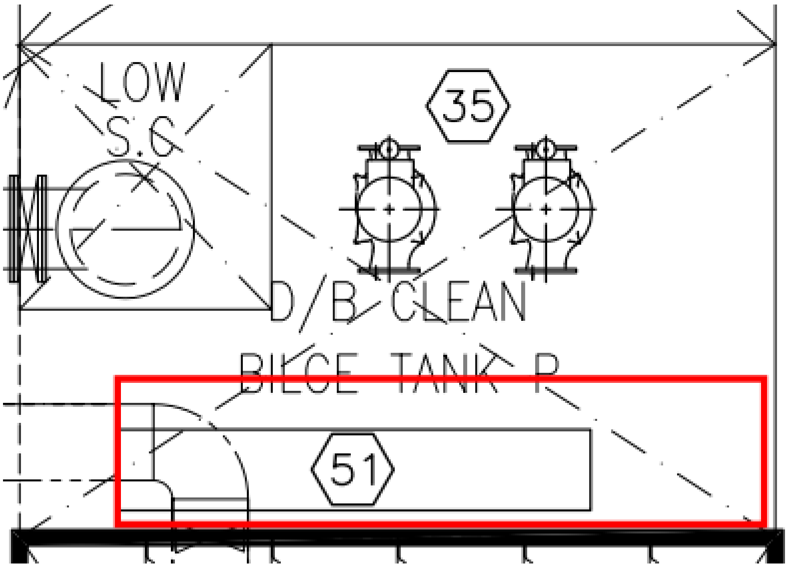

Figure 34: WSE Unitor reserved area

Figure 34 above shows the approximate reserved area for WSE Unitor on this ship. As previously stated, the max width is from the filter diameter, and this might result in a minimum distance between ballast pumps and filter to be approximately 0,6 meters. However, the area of concern is the height of the filter. From WSE, the maximum height of the filter is set to 2,615 meters.

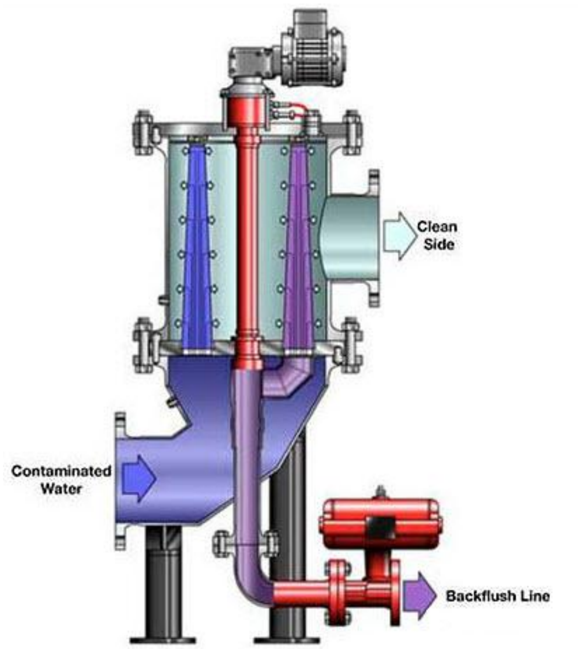

Figure 35: WSE Unitor filter

As previously stated, the minimum height available in the reserved area is 2,14 meters. This is due to the ventilation shaft seen at the lower left part of figure 34. The maximum height available is unknown, but it is assumed to be approximately 2,7 meters. If the filter is installed in fore most part of the reserved area (right hand), it will most likely fit.

This shows that it is possible to install WSE Unitor on this, however it will require some additional engineering compared to conventional systems, as the reactor unit have to be installed before the ballast pumps, and the filter after the ballast pumps.

7.5.2 Installation costs

It is assumed that a doubling of piping length required for installing WSE Unitor when compared to a conventional system. While this is a significant increase, it will not give a significant increase in the installation costs. It is estimated that the total price for installing WSE Unitor is $160.000.

Piping cost	
Pipes	$4 096
Bends	$716
Valves	$35 000
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$467
Switchboard work	$5 000
Switch	$0
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$163 479

Table 23: WSE Unitor installation costs

7.1.5.3 Operational costs

For operational costs, very little is known for WSE Unitor. However, the primary consumable in the system is most likely the electrodes. With an estimated lifetime of approximately 1200 hours in operation, it is possible to calculate a time interval. As previously stated, this ship will most likely fill the ballast tanks to about 90% of total capacity each ballast operation, and will have approximately 25 ballast operations yearly. This means the electrodes have to be replaced after 190 ballast operations or after 7 years in operation.

In addition to a periodical change of electrodes, WSE Unitor will increase the yearly fuel consumption with approximately 0,6 ton fuel. This shows that the operational costs for WSE Unitor will most likely be insignificant when compared to the installation and investment cost.

7.5.4 Reliability

Unfortunately it is not known what type of Ozone generator Unitor uses. While this does not matter, as the major difference between the different types is the power requirements, some actually require an air purifier for removing humidity in the air.

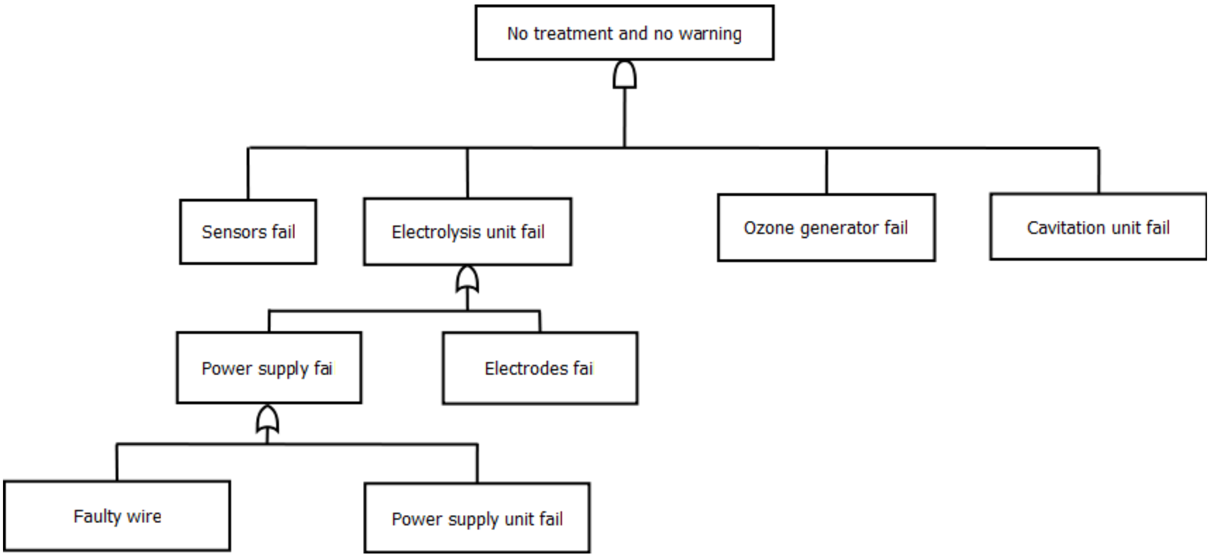

Figure 36: WSE Unitor fault tree

As with the previous system, no statistical data is available for the components in the system. This means that the fault tree is just an overview of the components that will have to fail in order for the worst case scenario occurs. This scenario is that the treatment system fails, and the sensors fail to report any fault with the system. This means that there is a possibility that the discharged ballast water is not according to regulations. This might result in a fine and downtime as well. Again, it is assumed that the sensors are the weakest link, but as the fault tree shows, both the sensors and the treatment units have to fail in order to the scenario to occur.

7.5.5 Lost time

As WSE Unitor performs the treatment before the ballast pump, it might be possible to halve the capacity without destroying the ring ballast piping system. However, the pressure loss by installing WSE Unitor is significant, where the max projected pressure loss for this system is 1,1 Bar. This will result in 2 hours lost time for 2x350 m^3/hr systems, when assuming the ship will fill the ballast tanks to 90% of total capacity each time.

By halving the capacity the lost time would be approximately 11 hours per ballast operation. This is a significant change in time spent in port, and a thorough analysis on time spent in port will be required before a decision is made.

7.6 NK-O3 BlueBallast System

BlueBallast is a Ozone based treatment system. It consists of one side stream injection unit and an Ozone generator. The side stream injection unit diverts parts of the flow, and injects Ozone in to the ballast water, before rejoining the main flow. Ozone is a highly volatile substance. When it comes in contact with seawater, it will quickly be dissolved, and create secondary treatment substances.

As Ozone is a highly corrosive substance, the side stream injection unit is made of high grade stainless steel. This will also protect the ballast water piping and tanks, as most of the Ozone will be dissolved before the side stream joins the main flow, and all Ozone will be dissolved before entering ballast tanks.

The main advantages with NK-O3 BlueBallast system is the simplicity of the system. The flexible components makes it easy to install, and the fact that the only component that needs to be in line with the ballast water pipes is the side stream injector makes it very easy and fast to install.

7.6.1 Location

BlueBallast is divided into several components, many of them is a part of the Ozone generation. As previously stated, only the side stream injection unit have to be installed in line with the ballast water piping.

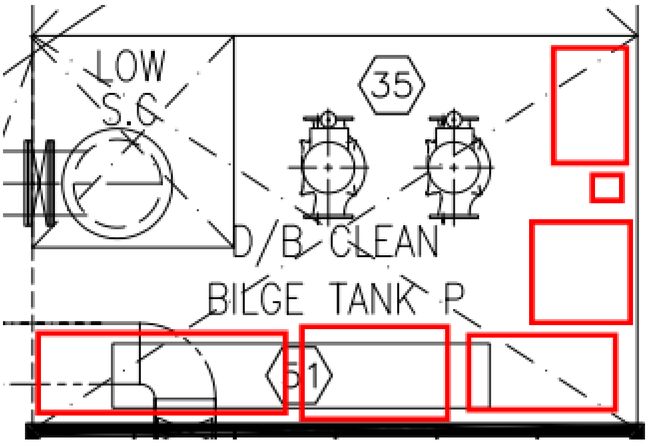

Figure 37: NK-O3 BlueBallast estimated area

Figure 37 above shows the estimated area required by the BlueBallast system. Instead of just adding the treatment unit, each component is shown as an estimate in the figure. While this figure contains the majority of the components BlueBallast requires, some key components are missing. Most notably they air receiver, oxygen receiver and ozone destructor is missing, and there is no room in the allocated space for them. Additionally, the distance between the top right component and ballast pumps are approximately 0,4 meters, which might prove to be a bit small when performing maintenance. Additionally, the height of the bottom left component is 2 meters and the minimum height available below the ventilation shaft is 2,14 meters.

However, NK claims the system is extremely flexible in terms on where the components is placed, and the engine room arrangement shows that it will be possible to place them elsewhere, and if necessary on a different deck. However, this estimate shows that special care should be taken to placing the components in order to ensure each component is within a reasonable distance from the ballast pumps.

7.6.2 Installation costs

NK was the only vendor to supply an estimate of installation cost in their reply to KGJS questionnaire. While this is supplied, an estimate from included workbook is used, in order to compare results with other vendors.

As only the side stream injection component is the only one installed in line with the ballast water piping, the piping length and bends required for installation is close to none. However, it is assumed that some piping work will be required regardless. The total estimated installation cost is approximately $165.000 which is significantly higher than what NK supplied in the questionnaire. It is hard to determine why the difference is this high, but most likely NK only included the actual installation, and related work, and excluded engineering costs.

Piping cost	
Pipes	$1 024
Bends	$358
Valves	$28 000
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$467
Switchboard work	$5 667
Switch	$11 958
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$165 673

Table 24: BlueBallast installation costs

7.6.3 Operational costs

While the questionnaire contained very little information regarding operational costs, some where available from an earlier internal study in KGJS. As earlier, it is assumed that the ship will fill the ballast tanks to 90% of total capacity every ballast operation, and that it will perform 25 ballast operations yearly. This results in an estimated operational cost of $900 yearly, which is insignificant when compared to installation and investment cost.

In addition to the maintenance cost, BlueBallast will increase the yearly fuel consumption with approximately 2 tons.

7.6.4 Reliability

As previously stated, the BlueBallast system is a very simple system and very few components needs to be installed in line with the ballast water piping. The fault tree, below, assumes that the worst case scenario is that the treatment is not according to regulations, and the system gives no warning about the failure.

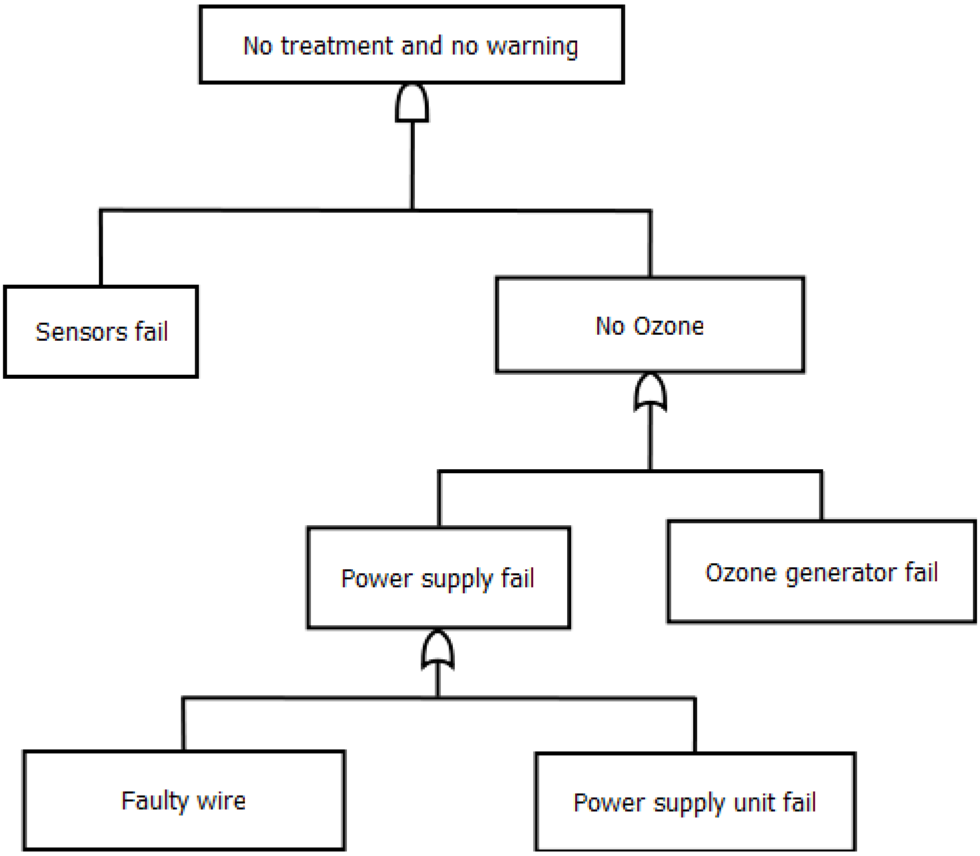

Figure 38: BlueBallast fault tree

In addition to the faults listed in the tree above, it might be important to note the health aspect of this system. As ozone is a dangerous substance, the room where the ozone generator is installed is equipped with an ozone detector. If this sensor detects a concentration of ozone above 0,2 ppm it will shut down the ozone generator, which means that the system will not treat the ballast water.

However, BlueBallast only treats on inlet, while during ballast water discharge only the neutralizing system is running, and applying a neutralizing agent as needed. This means that even though the ozone generator is not functioning, the ship can still discharge ballast water, but will not be able to load any additional ballast water.

7.6.5 Lost time

As BlueBallast will only treat ballast water on inlet, while during outlet only the neutralizing system will be running, it will be possible to halve the capacity of the treatment system. Additionally, as the system will inject the treatment in a side stream, instead of in the main flow, there is virtually no pressure loss induced by installing BlueBallast. This leads to a total lost time of 6 hours by halving the capacity, which is significantly lower than the other systems reviewed here. However, it might not be feasible, depending on how the neutralizing system is working.

7.7 Hyde Guardian

Hyde Guardian is a low pressure UV system, meaning the UV lamps emits UV lights with a wave length between 254 nano meters to 264 nano meters. Unlike Alfa Laval and OptiMarin, it load based treatment, meaning the power requirement are different with different water quality. The basic principle is that UV treatment is more effective in clear water, with low sediment load, while it is less effective in murky water, with high sediment load. This also significantly increases the lifetime of the UV lamps.

The main advantages of Hyde Guardian are the low power requirement, the investment cost and the simplicity of the system.

7.7.1 Location

Hyde Guardian is a fairly simple system, consisting of few components. However, as it is a UV system, it will be relatively long. The approximate dimensions for this ship will be 5 meters x 1,1 meters (length x breadth). The reserved area is approximately 3 meters x 0,5 meters (length x breadth). 5 meters will be too large to fit in the area close to the ballast pumps, but by separating the components, and placing the control cabinet on the fore bulkhead, the length will be acceptable.

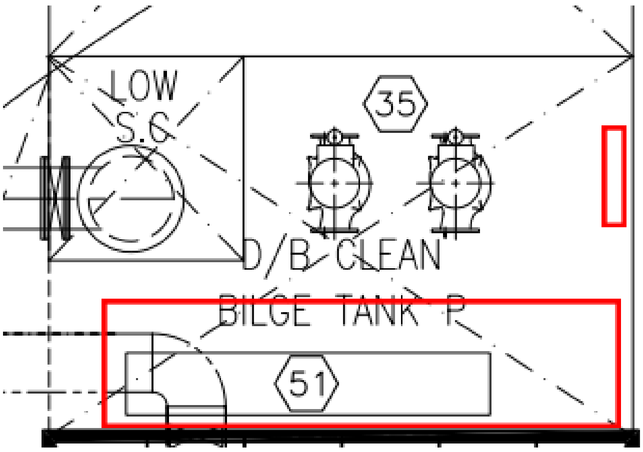

Figure 39: Hyde Guardian estimated area

Figure 39 above shows an estimation of the area Hyde Guardian will use. The distance between the ballast pumps and the system will be approximately 0,5 meters. As figure 39 shows, both the length and the breadth might be a bit too high for proper access to the system. However, this use max length x max breadth, so the actual installed system might be acceptable. This shows that special care on placing the components will be necessary when installing Hyde Guardian.

7.7.2 Installation costs

As previously mentioned, Hyde Guardian scales the power consumption based on the water quality. This means the nominal power requirement is much lower than that of OptiMarin and Alfa Laval, and as will as well significantly increase the life time of the UV lamps. However, for the installation cost, maximum power requirement is used, rather than nominal. This leads to a total installation cost o $155.000, which is significantly lower than Alfa Laval. This is primarily caused by the significantly lower power requirement.

Piping cost	
Pipes	$2 048
Bends	$358
Valves	$28 000
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$467
Switchboard work	$5 333
Switch	$0
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$154 406

Table 25: Hyde Guardian installation costs

7.7.3 Operational costs

From Lloyd's Register "Ballast water treatment technology: Current status" (2007) [11] it was found that Hyde Guardian will cost $10 per 1.000 m^3 treated ballast water. With the assumption that the ship will fill the ballast tanks to 90% of total capacity each ballast operation, and perform 25 ballast operations yearly, it will total to a yearly cost of $1.125. This is significantly higher than any other system reviewed in this analysis; however it is assumed that it also includes cost of fuel consumed due to the extra power consumption.

As this is a UV system, it is assumed that the primary maintenance would be exchanging UV lamps. The lamps have an expected life time of 8.000 hours in operation. This means that the lamps will have to be changed after 1.000 ballast operations, or after 40 years. This again shows that the maintenance intensity of a UV system is very low, and should be considered insignificant.

Installing Hyde Guardian will increase the yearly fuel consumption with approximately 2 tons.

7.7.4 Reliability

The basic assumption is that the worst case scenario is that the treatment system fails and that the operator gets no warning. The figure below shows the associated fault tree with this scenario.

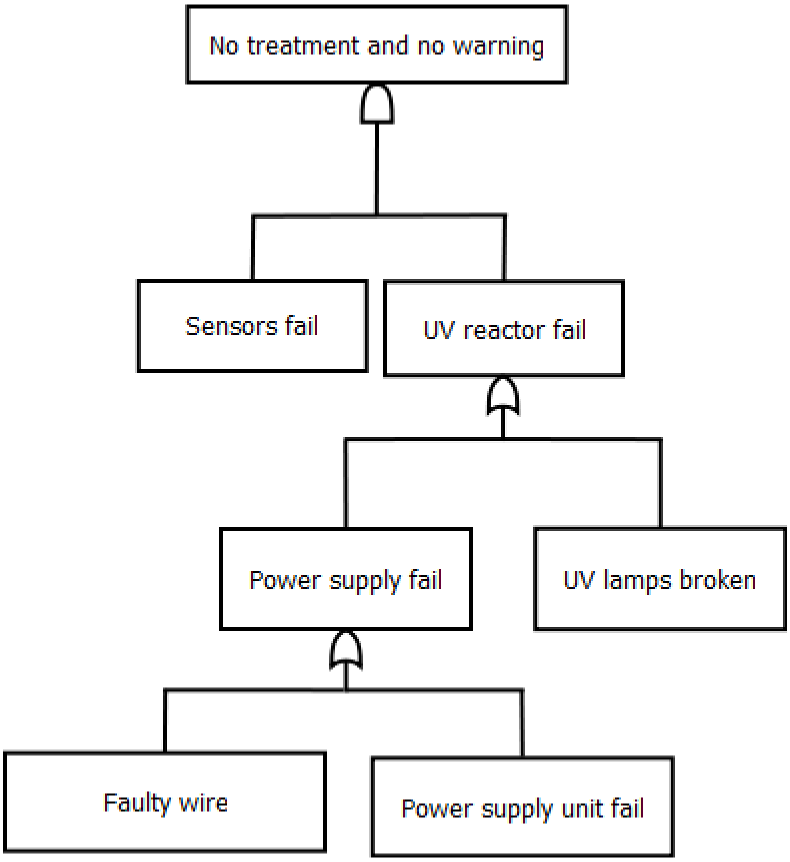

Figure 40: Hyde Guardian fault tree

Figure 40 above is the exactly the same as figure 21, or the fault tree for OptiMarin. This shows just how similar these two systems are, the primary differences is that Hyde Guardian use a load based system based on water quality for power consumption and the filter. As for the reliability, it is assumed that both OptiMarin and Hyde Guardian will have similar reliability.

7.7.5 Lost time

As a UV system, Hyde Guardian has to treat on both inlet and outlet of ballast water. This means that halving the capacity will not be possible, or very unlikely. However, the time lost due pressure loss is 1 hour, which is fairly insignificant.

7.8 Conclusion

The detailed analysis showed some interesting differences between the recommendations the model made. It showed that it is possible to install all systems, but for some available space might be an issue. It also showed that operational costs are insignificant when comparing it to installation and investment costs. This also includes the increase in fuel consumption, which at most is around 6 tons yearly. The reliability analysis is fairly inconclusive, as the statistical data is missing. However, it did prove a significant similarity between systems, and thus it is likely that most of these systems have a comparable reliability.

However, the operational cost analysis showed that for each system the operational costs will most likely be insignificant. The largest found in this study was around $1.000 yearly, including fuel consumption. A ship of this size will cost $5.000 - $10.000 daily in operational cost, and installing a ballast water treatment system will increase this cost with $1 - $5.

For investment cost, the difference is small, and at most is around $200.000, or the cost of installing one system. For installation cost, the difference is $5.000 - $20.000, and it was seen that the primary cause for this difference were the power requirement. This is especially apparent when comparing Hyde Guardian and OptiMarin Ballast System, where the primary difference is the power requirement.

System	Installation cost
OptiMarin Ballast System	$180 000
Alfa Laval PureBallast	$180 000
TechCross Electro-Cleen	$150 000
WSE Unitor	$160 000
NK-O3 BlueBallast	$165 000
Hyde Guardian	$155 000

Table 26: Systems installation cost

This study also showed that using a UV system will most likely be the most attractive option for this ship. Among all the systems, UV based systems were consistently among the cheapest to install, and the least complex systems. Of the UV systems, both Hyde Guardian and OptiMarin are attractive options, as the Alfa Laval system is only available as either 2 x 250 m^3/hr system or 2 x 500 m^3/hr system, which will either increase lost time or investment cost significantly.

As for OptiMarin, the only disadvantage is the price. Of the 7 systems reviewed here, OptiMarin have the highest investment cost, and the highest installation cost. Additionally, among the three UV systems reviewed here, OptiMarin's UV lamps have the shortest expected life time. This means that a pure cost analysis will favour Hyde Guardian as the best option for this ship. However, it might be an issue with space, and a more detailed analysis might be required to further investigate this system. It might also be of note that the space estimations, and power requirements for OptiMarin Ballast System is based on a 300 m^3/hr system. The analysis shows that the easiest installation is for OptiMarin, but it will also be the most expensive system, in terms of investment and installation costs.

For this ship a decision have to be made by considering system simplicity. For investment and installation cost it should be noted that Hyde Guardian, based on the received information, has a significantly lower overall cost compared to OptiMarin Ballast System.

8 Case study: Bulk carrier

M.V. Corrella Arrow was delivered in May 2009, with a total ballast water capacity of approximately 20.000 m^3 it will be among the first vessels that have to be in compliance with the ballast water convention. The ship has 2 x 1100 m^3/hr ballast pumps, however the model only contain data for systems capable of treating 1.000 m^3/hr, but this is adjusted for in the time lost analysis, where the actual treatment capacity is used. One of the major challenges with this ship will be finding an area were the treatment system can be installed.

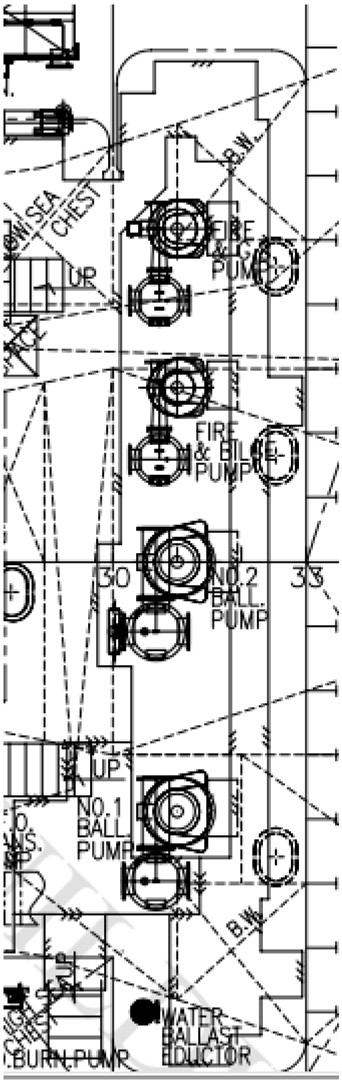

Figure 41: Corrella Arrow ballast pumps

As seen in the figure above, there is not much room available around the ballast pumps, additionally there is allot of piping in that area. The main engine is located just aft of the ballast pumps, which further complicates placing the treatment system. The figures below shows pictures of the area of Corrella Arrows sister ships, Tuju Arrow, where the engine room block is not fitted, and Macuru Arrow.

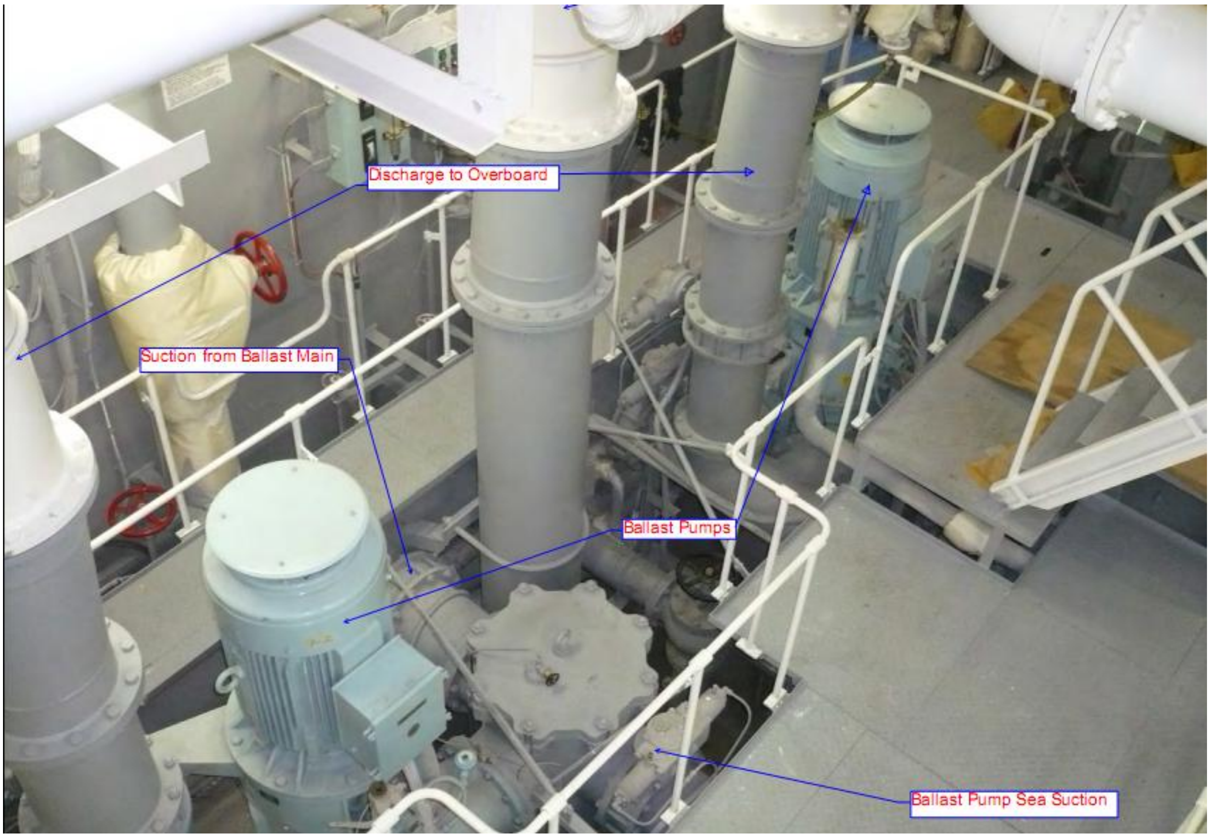

Figure 42: Macuru Arrow ballast pumps

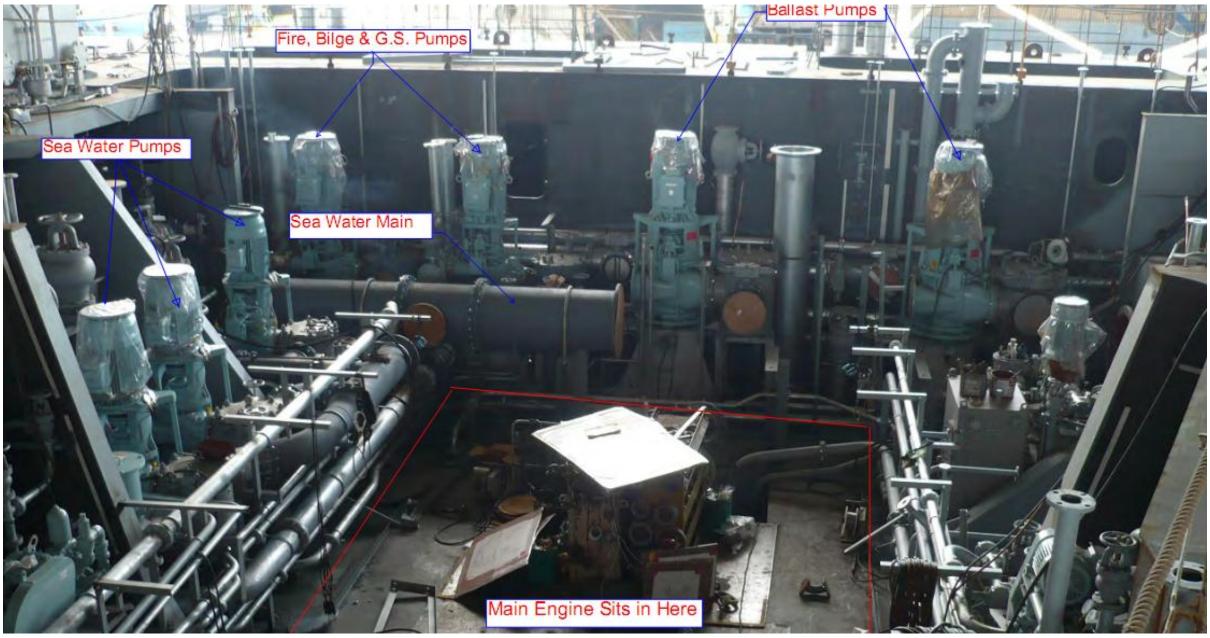

Figure 43: Tuju Arrow ballast pumps

Figure 42 and 43 shows just how little room there is around the ballast pumps, which means that the treatment system will have to be placed elsewhere in the engine room.

In addition to the space limitations, only systems that treat on inlet will be considered for this ship. As previously mentioned, it might be possible to halve the capacity on inlet, without increasing the time at port, as this type of ship uses its own cargo handling equipment when unloading. According to KGJS, as long as the ship is deballasted in approximately 24 hours it will have minimal impact on the ships operation. Additionally, the ballast P&ID for this ship is similar to that of the cement carrier described in chapter 7, it has a ring system so that each ballast pump can fill either the starboard or port side ballast tanks. This means that additional engineering is required to keep the ring system when using only one treatment system.

Power requirement will not be an issue for this ship, as bulk carriers are dimensioned according to the requirement for the bow thrusters. However, the during cargo service (unloading or loading cargo), the maximum power consumption is approximately 1.700 kW, with 1 x 1.200 kW generator and 1 x 750 kW generator running.

Generator	#	Effect
Main generator	2	1.200 kW
Main generator	1	750 kW
Em'cy generator	1	120 kW

Table 27: Corella Arrow generators

During cargo service, minimum available power will be 250 kW, which will be sufficient for most treatment systems.

8.1 Model recommendations

As mentioned, for this ship, only the treatment systems that treat on inlet only are desirable candidates. This excludes all UV treatment systems, and most asphyxiation systems, as both these technologies require treatment on outlet. From the technical evaluation, the systems in table 28 below were found to be applicable:

System	Comments
OptiMarin Ballast System	None
Alfa Laval PureBallast	None
OceanSaver	High pressure loss High investment cost
EcoChlor Ballast Water Treatment System	None
TechChross Electro-Cleen	None
Hyundai HiBallast	None
RWO CleanBallast	High footprint High investment cost
Hyde Guardian	None
N.E.I. Venturi Oxygen Stripping	High pressure loss
Wilhelmsen Ship Equipment Unitor	High pressure loss Required inlet pressure is too high
Hitachi ClearBallast	None
NK-O3 BlueBallast	High pressure loss
JFE Engineering BallastAce	None

Table 28: Technical evaluation recommendations

By cross referencing with the KPI evaluation, it is possible to further exclude OptiMarin Ballast System, Alfa Laval PureBallast, OceanSaver, RWO CleanBallast and JFE Engineering BallastAce. There are still 8 systems that need to be evaluated. However, KGJS will not accept any system that requires treatment on outlet for this ship, which further excludes Hyde Guardian.

System	Comment
EcoChlor Ballast Water Treatment System	None
TechCross Electro-Cleen	None
Hyundai HiBallast	None
N.E.I. Venturi Oxygen Stripping System	High pressure loss
Wilhelmsen Ship Equipment Unitor	High pressure loss Required inlet pressure is too high
Hitachi ClearBallast	None
NK-O3 BlueBallast	High pressure loss

Table 29: Corrella Arrow applicable systems

From this it is further possible to eliminate several systems. EcoChlor is a chemical based system, which requires chemical tanks and storage of chemicals, which significantly increase the footprint of the system. KGJS have discarded all systems that require chemicals that are not produced in line, which will exclude EcoChlor from this ship. N.E.I. Venturi Oxygen Stripping System has, as previously stated in chapter 7.1, an uncertain approval from three different flag states, which makes it hard to recommend installing this system.

System	Reason
EcoChlor Ballast Water Treatment System	Chemicals required
Hyundai HiBallast	High footprint, and only have a basic approval
N.E.I. Venturi Oxygen Stripping System	Uncertain status regarding active substance
Hitachi ClearBallast	Complex and large system

Table 30: Discarded systems

Table 30 above shows the discarded systems. This reduces the list to TechCross Electro-Cleen, Wilhelmsen Ship Equipment Unitor and NK-O3 BlueBallast as the only applicable systems for this ship.

As the reliability study will not differ from the study from chapter 7, this will be discarded for this ship, as all systems included are already examined in chapter 7.

The full model recommendations are available in appendix 6 (technical evaluation) and appendix 7 (KPI evaluation).

8.2 TechCross Electro-Cleen

Electro-Cleen is an electrolysis system, using hypochlorite as active substance. By applying a mild current to the seawater, the treatment system will produce hypochlorite in line, which an effective germicide. Electro-Cleen requires the ballast water to be treated both on inlet and outlet, and it is possible that the discharged ballast water needs to be neutralized before entering the ocean.

Among the negative side effects is the possibility for corrosion. According to Song, Dang, Chi and Guan chlorinated seawater will increase corrosion rate 1.3 - .1.7 times compared to that of natural seawater [13]. However, it is not known how coated ballast tanks will be affected by electro chlorinated seawater.

8.2.1 Location

The dimensions are based on the EC-1200 system, which has a capacity of 1.200 m^3/hr. Unlike the cement carrier, this ship does not have any reserved area for ballast water pumps. For EC-1200 the dimensions of the electrolysis module is 1.84 x 0,51 x 1,7 meters (length x breadth x height) [17].

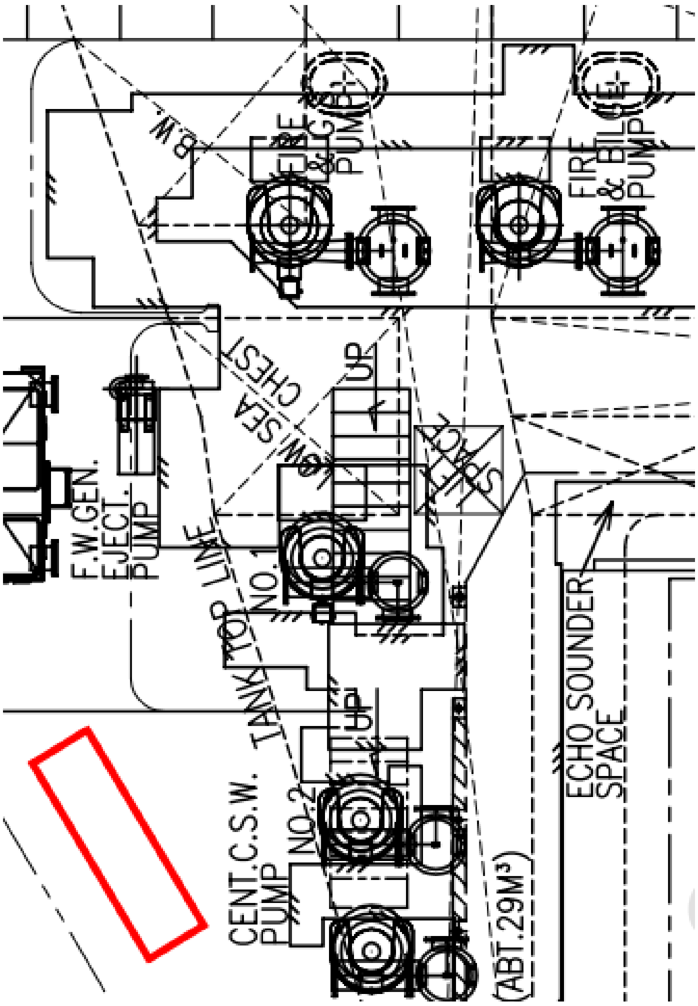

Figure 44: Electro-Cleen estimated area

Figure 44 above shows a suggestion to point of install for Electro-Cleen EC-1200. This is the only area, on the same deck as the ballast pumps, where it is possible to place the treatment system, or the same space on the starboard side.

8.2.2 Installation cost

As seen from figure 44, the distance from the installed treatment system to the ballast pumps is significantly longer than for the cement carrier. Additionally the power requirement is significantly higher or approximately 3 times that of the cement carrier.

The installation costs totals at approximately $180.000.

Piping cost	
Pipes	$5 120
Bends	$537
Valves	$38 500
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$933
Switchboard work	$5 667
Switch	$11 958
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$180 915

Table 31: Electro-Cleen installation costs

8.2.3 Operational costs

As operational costs will be dependent on time in operation, it is natural to assume that for this ship the operational costs will be larger than for the cement carrier. This ship has a total ballast water capacity of approximately 20.000 m^3, and it is estimated that it have 100 ballast operations yearly. Of these, 30% will fill the ballast tanks to 25% of total capacity, 30% to 50% of total capacity and 40% to 90% capacity. This equals to approximately 630 hours in operation for this ship, while for the cement carrier it will be approximately 100 hours in operation yearly. This means the maintenance cost is most likely to exceed that of the cement carrier, but there is not enough information available to calculate how much more.

In addition to the maintenance cost, the treatment system will increase the yearly fuel consumption with approximately 12 tons.

8.2.3 Lost time

As previously stated, KGJS considers installing only one treatment system for this ship, thus halving the ballast pump capacity, and also the investment cost. As this type of ships use own cargo handling system for unloading, the cargo unloading will take significantly longer than cargo loading, where shore equipment can be used. This means the ballast pumps are dimensioned for loading rates, and not unloading rates, while some treatment system only treats on intake, or while unloading. KGJS is interested in examining the possibility of using only one treatment system, which treats on intake, and thus halving both the capacity and investment cost.

For TechCross Electro-Cleen the total time spent filling the ballast tanks to 90% of capacity, with only one treatment system, were approximately 20 hours. This also adjusts for pressure loss induced by installing the treatment system. According to KGJS, as long as the ship is able to fill the ballast pumps within 24 hours, it will not increase the time at port. For TechChross Electro-Cleen, this is possible.

However, it should be noted that some redundancy will be removed from the ballast system on the ship. Even though it is assumed that it is possible to engineer a solution so that both pumps can be used on a single system, it will still be only a single system. If this system fails, the ship cannot take up more ballast water, and it will most likely lead to downtime. With two installed system, there is a redundancy so that if one system fails, the other are still running, and the ship can still operate, however, with significantly reduced ballast capacity both on intake and outlet.

8.3 Wilhelmsen Ship Equipment Unitor

WSE Unitor consists of 4 treatment units, while most systems only have 2 or 3 treatment units. While adding components will increase the complexity of the system, in this case it will reduce the max power requirement for the system. As the system is primarily based on electro chlorination, a process which is dependent on the salinity in the water; low salinity will equal high power consumption

The main benefits from using WSE Unitor are the small footprint, low power requirement and only one way treatment (only on intake). However, all treatment are performed before the ballast pumps, meaning that there is a risk of damage to the ballast pumps due to either corrosion or cavitation in the pump. While WSE claims this will not be a problem, it should be noted, and in case of ballast pump breakdown, the impeller and similar should be checked for corrosion and cavitation damages.

While the reactor chambers are located before the ballast pumps, filters will be located after the ballast pump.

8.3.1 Location

As WSE Unitor requires the reactor unit to be before the ballast pumps, while the filter after the ballast pumps, engineering for this system might be a bit more complicated than for other systems. For this study, it is assumed that the reactor is fitted on the ballast piping before the ballast pumps, and the filter is the only component requiring additional space.

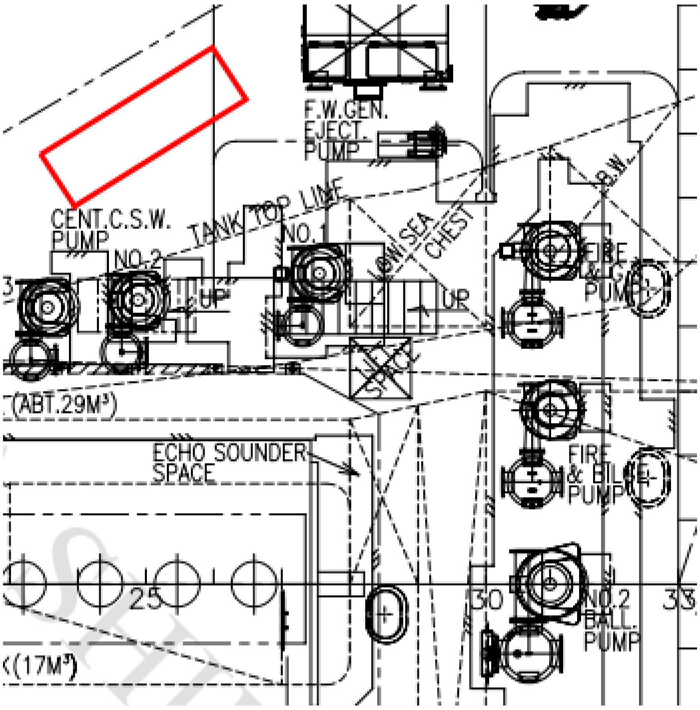

Figure 45: WSE Unitor estimated area

Figure 45 above shows the estimated area the filter will take. As with Electro-Cleen, this is most likely the only area on the same deck where there is enough free space for the system to be installed. It might be possible to place it elsewhere, by building a platform, above any interfering component.

8.3.2 Installation costs

As one of the primary benefits of using WSE Unitor is the low power requirement, and the main costs of installing a treatment system is related to electrical work, this system is among the cheapest to install. However, the required inlet pressure is higher than what the ballast pumps are operating at, which will most likely increase the installation cost. It is possible to change the inlet pressure by changing the pump impeller, or it might be necessary to install a booster pump.

Without including any changes to the pumps, or an additional pump, the installation costs are estimated to be approximately $170.000, which is significantly cheaper than Electro-Cleen.

Piping cost	
Pipes	$5 120
Bends	$537
Valves	$38 500
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$933
Switchboard work	$5 000
Switch	$0
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$168 290

Table 32: WSE Unitor installation costs

8.3.3 Operational costs

It is assumed that the primary maintenance cost will be from replacing electrodes in the electrolysis unit. These have an estimated lifetime of 1.200 hours in operation, and with an estimated 820 hours in operation a year, these have to be changed after 1 year and 6 months. Even though it is probably more consumables for the system, it is assumed that changing the electrodes will be the most the primary cost for this system, and the simple estimation shows that this will probably be negligible compared to the investment and maintenance cost.

In addition, WSE Unitor will increase the yearly fuel consumption with approximately 2 tons.

8.3.4 Lost time

AS previously stated, KGJS is interested in installing only one treatment system on this ship. It is assumed that the ship will fill the tanks to maximum 90% of total capacity, which will take approximately 25 hours with only one ballast pump, including reduced capacity due to pressure loss.

While this is slightly higher than the initial limit set, 24 hours, it will most likely not affect the ships time at port, as in most situations the ship will spend 24 – 30 hours unloading, and the ship will not leave immediately after the unloading is complete.

8.4 NK-O3 BlueBallast

BlueBallast is a Ozone based treatment system. It consists of one side stream injection unit and an Ozone generator. The side stream injection unit diverts parts of the flow, and injects Ozone in to the ballast water, before rejoining the main flow. Ozone is a highly volatile substance. When it comes in contact with seawater, it will quickly be dissolved, and create secondary treatment substances.

As Ozone is a highly corrosive substance, the side stream injection unit is made of high grade stainless steel. This will also protect the ballast water piping and tanks, as most of the Ozone will be dissolved before the side stream joins the main flow, and all Ozone will be dissolved before entering ballast tanks.

The main advantages with NK-O3 BlueBallast system is the simplicity of the system. The flexible components makes it easy to install, and the fact that the only component that needs to be in line with the ballast water pipes is the side stream injector makes it very easy and fast to install.

8.4.1 Location

As previously mentioned, BlueBallast consists of several components, all critical for operating the system. The only component that needs to be installed in line with the ballast water piping is the side stream injection unit, which will most likely fit on the ballast water piping just after the pump.

Figure 46 below shows the ballast pumps and the piping leading to the ballast tanks. While space is scarce along the pipe, the side stream injection unit does not require much space, as seen from figure 47.

Figure 46: Ballast pumps and piping

Figure 47: BlueBallast side stream injector

As the drawings detailing the ballast water piping below the deck are not available, it will most likely be possible to fit the side stream injector along the ballast water pipes as suggested. There are still several key components that need to be installed, among other the ozone generator, air compressor, air dryer etc. Figure 48 below shows a suggestion for placement of these components.

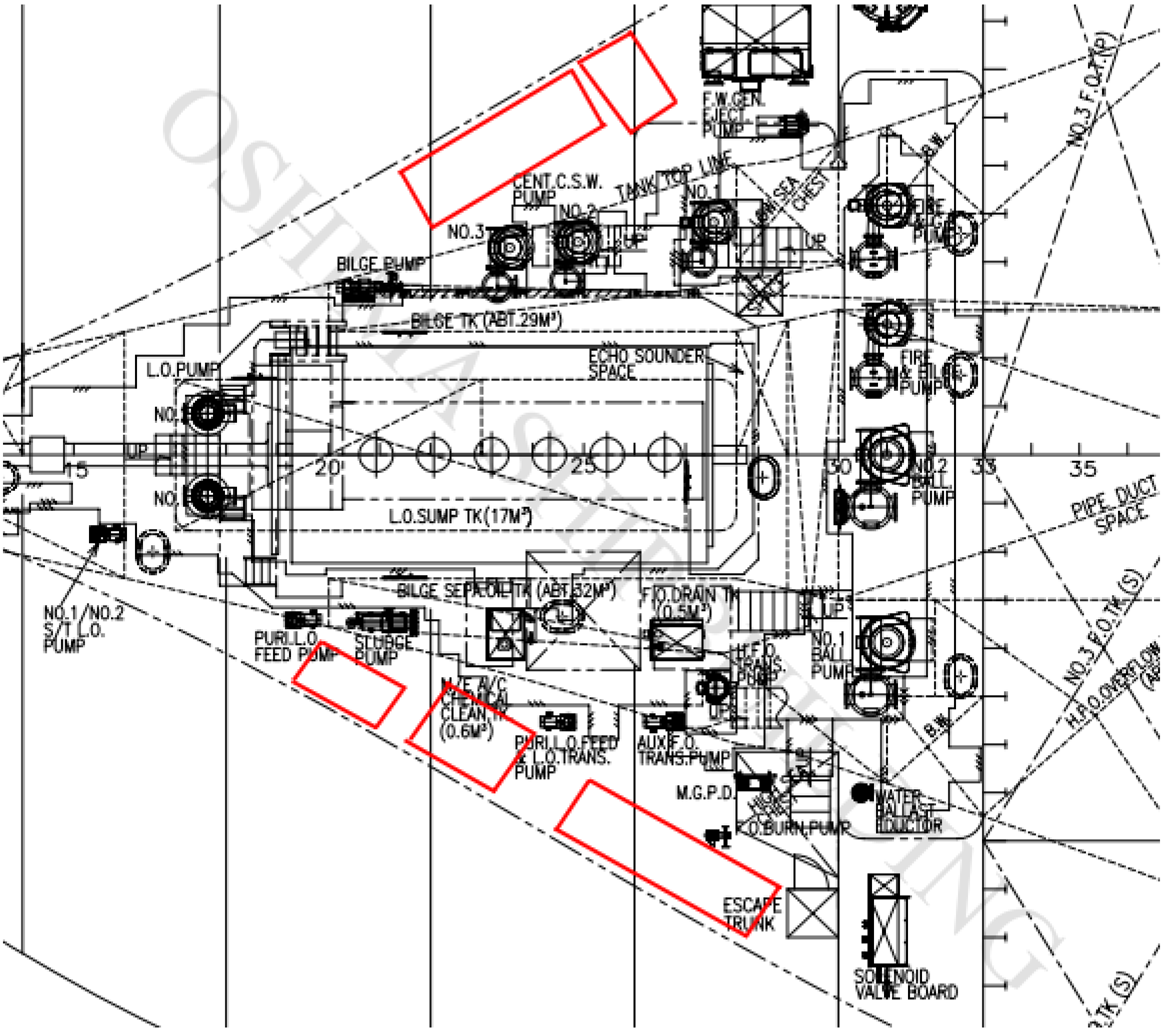

Figure 48: BlueBallast estimated area

The figure above shows the estimated area each component requires. It was assumed that all components have to be located on the same deck as the ballast pumps, or side stream injection unit, but if it is more flexible, it will be easier to place the components. This shows that there are no limitations in terms of available area when installing, assuming the side stream injection unit can be installed along the ballast piping. Additionally, the components are most likely more flexible than assumed here, and could be installed on other decks, which will further simplify placing them.

8.4.2 Installation costs

As previously mentioned, one of the key benefits of BlueBallast is the simplicity of the system, which makes it easy and quick to install. This is the primary reason KGJS finds the system interesting, as they will apply to vessels where a "quick fix" is necessary, and a quick and cheap installation process will be highly important.

As for the installation costs, it was found that the total cost of installing BlueBallast is approximately $180.000, which is about the same as both WSE Unitor and TechCross Electro-Cleen.

Piping cost	
Pipes	$512
Bends	$537
Valves	$38 500
Steel cost	
Steel	$1 000
Class / Commissioning costs	
Class	$6 000
Commissioning	$25 200
Electrical cost	
Cable	$1 400
Switchboard work	$6 000
Switch	$13 286
New switchboard	$50 000
Design & engineering	
Design	$20 000
Class approval	$6 000
Shipping	$10 000
Total	$178 435

Table 33: BlueBallast installation costs

8.4.3 Operational costs

For BlueBallast, a cost of treated per cubic meter treated ballast water is available. As previously mentioned, this ship will have approximately 100 ballast operations yearly, where 30% will fill the ballast tanks to 25% of total capacity, 30% will fill the ballast tanks to 50% of total capacity and 40% will fill the ballast tanks to 90% of total capacity.

This results in a yearly cost of $11.000 for operating the BlueBallast treatment system. This equals to approximately $30 per day, and for this ship the daily operating costs will be $6.000 – $10.000. This shows that the maintenance cost will be negligible when compared to the investment cost and operational cost. In addition, the BlueBallast treatment system will cause an increase of 18 tons in yearly fuel consumption.

8.4.4 Lost time

As with the other two systems, the time spent deballasting the ship when using only one ballast pump is of interest when deciding on a treatment system for this ship. When adjusting for the pressure loss induced by the system, it was found it will take 19 hours to completely deballast the ship using only one ballast pump. This is within the limit, which was set to 24 hours, which means that it is fully possible to use only one treatment system if BlueBallast is installed.

8.5 Conclusion

For Corrella Arrow the primary purpose is to identify whether or not it is plausible to install just one system, and thus halving the capacity of the ballast pumps. Secondary interests are installation costs and investment costs, while operational costs are considered to be almost negligible.

Of all the systems reviewed here, TechCross Electro-Cleen will have the highest cost when combining installation and investment cost. Additionally the system has to be fully disassembled every six months, which will significantly increase the workload for the engine room crew. However, the lost time analysis showed that it is possible to install only one Electro-Cleen treatment system, and halving the capacity, without increasing the time in port.

The cost of installing and purchasing WSE Unitor or NK-O3 BlueBallast are the same. As the systems are similar, it is hard to identify differences between the systems. Where Unitor use a reactor unit before the ballast pumps, BlueBallast use a side stream after the ballast pumps, and have minimum impact on the ballast water piping.

Both systems might have negative influence on the ship. BlueBallast use ozone as active substance, which is highly corrosive, it is uncertain whether or not this reaches the ballast tanks, or even is present when the side stream rejoins the main flow. Additionally, DNV has expressed some concerns about how effective ozone is, as an active substance, under different operational conditions.

Unitor has the reactor unit before the ballast pumps, with cavitation, and hypo chlorite is added to the water, it is unknown whether the cavitation enters the pump, and if there will be any residual hypo chlorite present in the pump after the ballast operation.

While both vendors say that neither system will have any negative effect on neither the ballast tanks nor the ballast pumps, it is hard to make any assumption as no experience data is publicly available. For this ship, WSE Unitor will most likely be the best option. It is small with low complexity, and will only require neutralizing if the retention time is lower than 3 hours. While the pressure loss is significant, some of it will be on the suction side of the pump, which means the actual pressure loss will be significantly lower than assumed here.

As the vendor does not supply a sampling system, which means it will most likely have to be developed separately, maybe in collaboration with the vendor. However, TechCross is the only vendor that supply a sampling system of the ones reviewed here.

9 Conclusion

The purpose of the thesis was to develop a decision support system for ballast water treatment systems, considering both technical and economical aspects of the system. Early in the work, it became apparent that the decision support model could exclusively recommend a single system, but only evaluate whether or not the system would be compatible to the given input data. However, by differentiating with a compatibility analysis (called technical evaluation) and a KPI analysis (called KPI evaluation), it was possible to exclude some system early in the process.

The technical evaluation compares the system data against the input data, and shows whether or not the system complies by the boundaries set by the user. Many possible alternatives where considered when developing the model, but the data available and the chosen tool, Microsoft Office Excel, imposed several limitations which made it hard to develop are more thorough system.

The KPI analysis uses a comparative grading system from 1 – 6, where 1 is the best grade and 6 is the worst grade. As a KPI analysis requires comparable values in order to analyze the results, all raw data was converted to grades. Additionally, the model also evaluates values that are either on or off (yes or no), which are not possible to include in a KPI analysis, as they would have too high influence on the final score.

For both case studies the model identified 6 – 8 systems that were applicable to the ships. By applying ship specific constraints, and additional knowledge of the systems it was possible to further eliminate several systems. This shows that detailed knowledge of each system that is evaluated will further help excluding systems.

For the economical analysis, it was found that installing a ballast water treatment system will increase the daily operating cost with $1 - $30, which is negligible when compared to the investment and installation costs. However, the data available for operational costs are limited, and should be considered as a rough estimate. The installation cost analysis was based on standardized prizes from Asian shipyards. The case studies showed the power requirement of a system is the most important factor when estimating the installation cost. A high power requirement will in most cases equal a high installation cost, while both the cost of piping and steel work will remain close to constant for a ship. The case studies showed that the primary costs of a ballast water treatment system will be the installation and investment cost, while the operational costs, including increased fuel consumption, will most likely be negligible.

For the cement carrier it was found two systems that were applicable to the ship; OptiMarin Ballast System and Hyde Guardian. The study showed that Hyde Guardian might be a bit too large for the designated area, but had the lowest cost for both investment and installation. OptiMarin Ballast System had the highest cost of the reviewed systems, but would most likely be the simplest system to operate and install.

For MV Corrella Arrow, WSE Unitor was found to be best option. However, the reactor unit is located before the ballast pumps which might have a negative effect on the pumps which should be monitored. The total cost of installing and purchasing NK-O3 BlueBallast would be approximately the same, but DNV have concerns regarding the efficacy of this system.

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