Ballast Water Treatment System Selection

Robin Fearnley, BEng(Hons), CEng, CMarEng, MIMarEST

BMT, Maritime House, 210 Lower Bristol Road, Bath, BA2 3DQ.

Tel: +44(0)1225 473 600

Synopsis

The enforcement date of the Ballast Water Management Convention (September 2017 for new builds and September 2019 for existing ships), coupled with the issues due to the United States Coastguard's (USCG's) reluctance to provide alternative management system approval certificates (which are in essence an extension to the need to meet their Ballast Water Management (BWM) standard which came into force in 2016), means that it is imperative that ship owners/operators who have not already done so investigate what their obligations are and what options they have for ensuring that their Ballast Water Management Plan meets the convention.

This paper takes the reader through the process of identifying what the best solution is for ship owners/operators based on their own fleet's (possibly unique) requirements. The paper shows in detail one case study, using a multi-criteria analysis (M-CA) tool, for the selection of a suitable ballast water treatment system if it is determined that one is required to be fitted. The paper also looks at different ship types and what specific factors may need to be considered based on their operational requirements.

Author Biography

Robin Fearnley is a Principal Marine Engineer with BMT. He is the capability lead for auxiliary systems in the company, acting as the focal point for auxiliary systems design and skills development for the naval engineering department. Robin often leads the engineering team on BMT wholeship design bids and over-seeing the development of alteration and addition work for in-service UK Royal Fleet Auxiliary ships. Prior to his time at BMT, Robin was time served as an engineering officer on large containerships with P&O Containers/P&O Nedlloyd Ltd as well as working as a coding surveyor with a UK Certifying Authority and dabbling in boat building.

NOMENCLATURE

Abbreviation	Definition
A&A	Alteration and Addition
ARM	Availability, Reliability and Maintainability
B	Breadth
BWM	Ballast Water Management
BWMC	Ballast Water Management Convention
BWTS	Ballast Water Treatment System
Dwt	Deadweight
EC	Electro-chlorination
HATS	Harbour Acceptance Trials
IMO	International Maritime Organisation
ISO	International Organization for Standardisation
LOA	Length Overall
LP	Low Pressure
M-CA	Multi-Criteria Analysis
MEPC	Marine Environment Protection Committee
OEM	Original Equipment Manufacturer
RFQ	Request for Quotation
RP	Refit Period
SATS	Sea Acceptance Trials
T	Draft
TRL	Technology Readiness Level
TRO	Total Residual Oxidation
UV	Ultraviolet
USCG	United States Coastguard
WIW	Work in way

1. INTRODUCTION & BACKGROUND

1.1. Statute and Legislation

IMO MEPC session 71 confirmed agreement on the implementation dates of, and therefore compliance to, the International Convention for the Control and Management of Ships' Ballast Water and Sediments, more commonly known, and herein referred to as the BWM Convention (BWMC) (Ref 1) . The whole ship impact of the BWMC has been widely discussed but, put simply, for all vessels which BWMC is applicable; a Ballast Water Treatment System shall be installed and operated in accordance with an approved Ballast Water Management Plan from circa 2024 at the latest.

1.2. United States Specific

The United States requirements for control of invasive organisms in Ballast Water largely align with the IMO BWMC; however two significant differences are discussed here:

1.2.a. The USCG issued rules for the management of Ballast Water in US Waters (Ref 2) and for type approval of Ballast Water Treatment Systems BWTS (Ref 3) which are in force now for all new builds and existing ships who want to discharge ballast water into US waters;

1.2.b. The USCG rules require USCG approval for BWTS, which need to demonstrate that all but a very small number of organisms which are discharged into US waters are dead, as opposed to IMO BWMC which requires all but a very small number of organisms are not viable (capable of surviving or reproducing)[1].

As a result of point 1.2.b above, at present, only a small number of IMO approved systems are also approved by the USCG. It requires considerably more energy for a BWTS to render organisms dead in the BWTS testing process; therefore, BWTS which have been designed to ensure organisms are not viable (in accordance with IMO testing), and optimised against ballast capacity, now may need to be redesigned to deliver more "destructive" power to the potentially invasive organisms.

2. BASELINE FOR ANALYSIS

2.1. Ship Specific Example

To put the Ship impacts into better context, an assumed reference vessel and operating profile will be used. Here we will consider a ship with the below principal particulars:

	Value
Vessel Type	Product Tanker
LOA	185m
B	33m
T	9m
Dwt	50,000mT
Cargo Tank Capacity (98% full)	64,000m^3
Ballast Tank Capacity	20,500m^3
Cargo Pump (x3) Capacity	1,000m^3/hr @ 1.6bar
Ballast Pump (x2) Capacity	500m^3/hr@ 3.2bar
General Service Pump Capacity	100m^3/hr @ 7bar

Table 1: Assumed Reference Vessel Principal Particulars

The above reference vessel will perform the below assumed voyage, considering a round trip from Singapore to Yokohama:

	Value
Duration	20 days
Number of Ports	2
Average Port Stay	20 hours
Journey Distance	~5800 miles

Table 2: Assumed Nominal Ship Voyage

[1] It should be noted that there is currently a legislative bill, which recently passed through the US Senate, looking to better align the USCG testing methods to those of the IMO.

The reason for defining the voyage particulars is specifically related with whether there is a need to provide a BWTS solution with USCG approvals or not. For the purposes of this paper it has been assumed that there are no plans to visit US. It is assumed that any alternative trade routes would continue to focus around the Far East. Therefore, compliance with USCG requirements has not been deemed necessary, nor has it been assessed despite the fact that there may be an argument to seek US coastguard compliance to cover all potential ballast discharge locations, provide some level of future-proofing and to perhaps provide some commonality should the owner/operator have other ships operating in US waters either now or in the future.

2.2. Shaping the assessment

After assessing the need to fit a BWTS to the ship (a step not covered in this paper), it is necessary to conduct a market research exercise, in conjunction with the ship owner/operator, in order to narrow the assessment of suitable solutions down to a manageable number of BWTSs. For the purposes of this paper, 3 candidate solutions were selected for assessment. This is the recommended minimum number when conducting a Multi-Criteria Analysis (M-CA).

For this analysis, the ship owner/operator has stated they are agnostic to the type of BWTS and therefore, due to the ship type (as will be shown, there can be an argument to fit a BWTS using electro chlorination (EC) technology on a tanker, even with relatively low flow rates involved), it was decided to assess two ultraviolet (UV) + filtration plants complying with the G8 standard of reference 1 and one EC plant complying with the G9 standard of reference 1.

Figure 1 below is a simple sketch of the existing ballast system onboard the tanker. The ballast tanks in way of the cargo tanks are served by duty/standby ballast pumps located in the Cargo Pump Room (only one pump shown in the sketch), whilst the aft peak tank, which is not contiguous with any cargo tanks, is served by a general service pump located in the Engine Room.

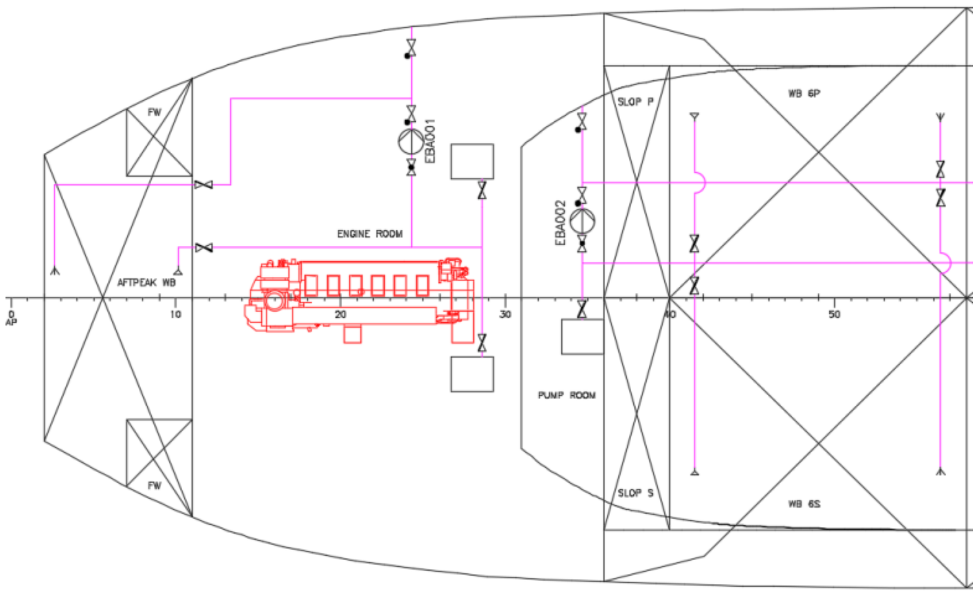

Figure 1 - Existing Ballast System

For the two UV + filtration systems, which require the ballast water to be treated on uptake and discharge, two separate BWTS are required: one suitable for use in a cargo pump room (e.g. Ex rated for use in a hazardous zone) and one more standard (but smaller) plant for treating the ballast water in the aft peak tank. A sketch of such a solution is presented in Figure 2. For both systems, it is likely that the ballast pumps and the general service pump will require uprating (with respect to pressure) in order to overcome the additional losses introduced by the BWTS equipment. Also, UV + filtration solutions are required to enter a back-flushing mode at regular intervals to ensure the back pressure across the filter element does not become too great. This back-flushing cycle means that an additional pressure loss needs accounting for, either by designing for increasing the output pressure of the ballast pumps or by fitting a dedicated back-flushing pump to the system (most suppliers offer the latter as an option as part of their scope of supply). It should be noted that the necessary uprating may not require a complete change of pump model. Depending on the pump and the range it comes from, it may be possible to match the new system properties through a change in impeller and accompanying change in motor whilst retaining the main pump casing.

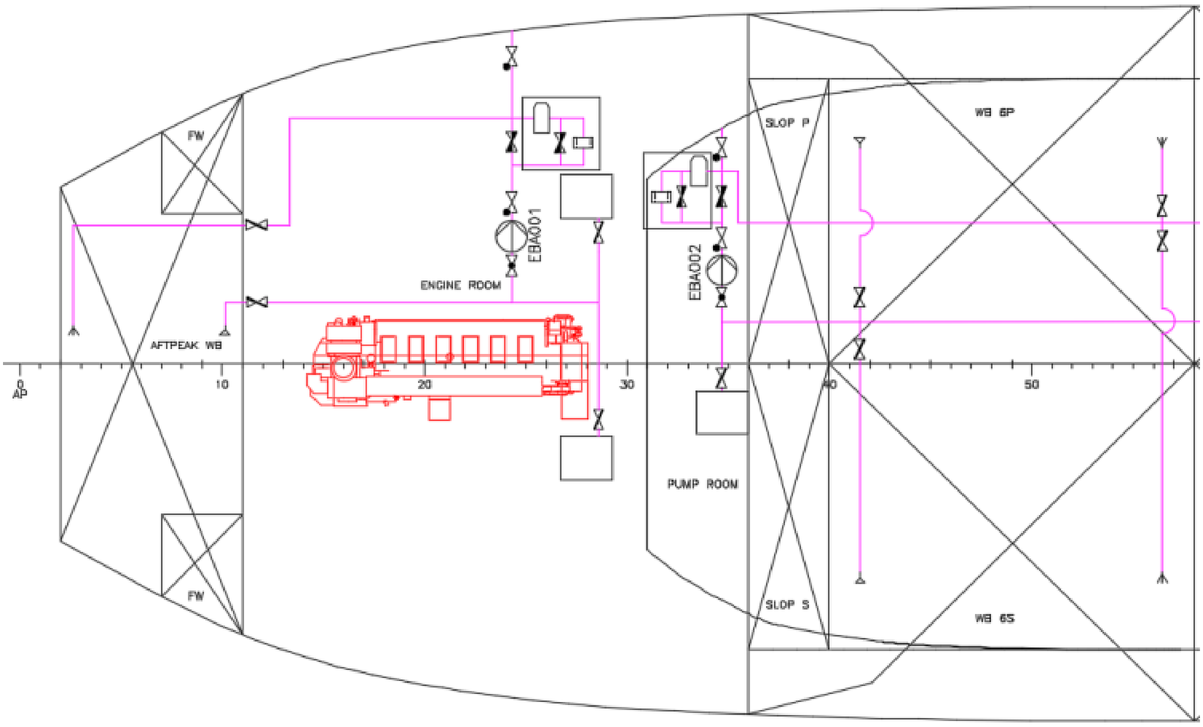

Figure 2 - Ballast System with UV + Filtration BWTS integrated

For the BWTS utilising electro-chlorination, treatment is only required on uptake (with neutralisation on discharge). This allows for a single plant solution, located in the Engine Room and thus minimising Ex rating of equipment (only the Total Residual Oxidant (TRO) sensor and neutraliser in the cargo pump room need to be Ex rated) but does require some relatively significant work with respect to pipework changes: supply to ballast tanks in way of the cargo tanks need to be routed via the cargo deck and through a physical isolation (such as a double block and bleed) when re-entering the hazardous area. The pump in the Engine Room also needs to be replaced with an uprated (flow rate and pressure matched to system requirements) model with two speed motor to allow for operation at 100m3/hr and 500m3/hr. A sketch of such a solution is presented in Figure 3.

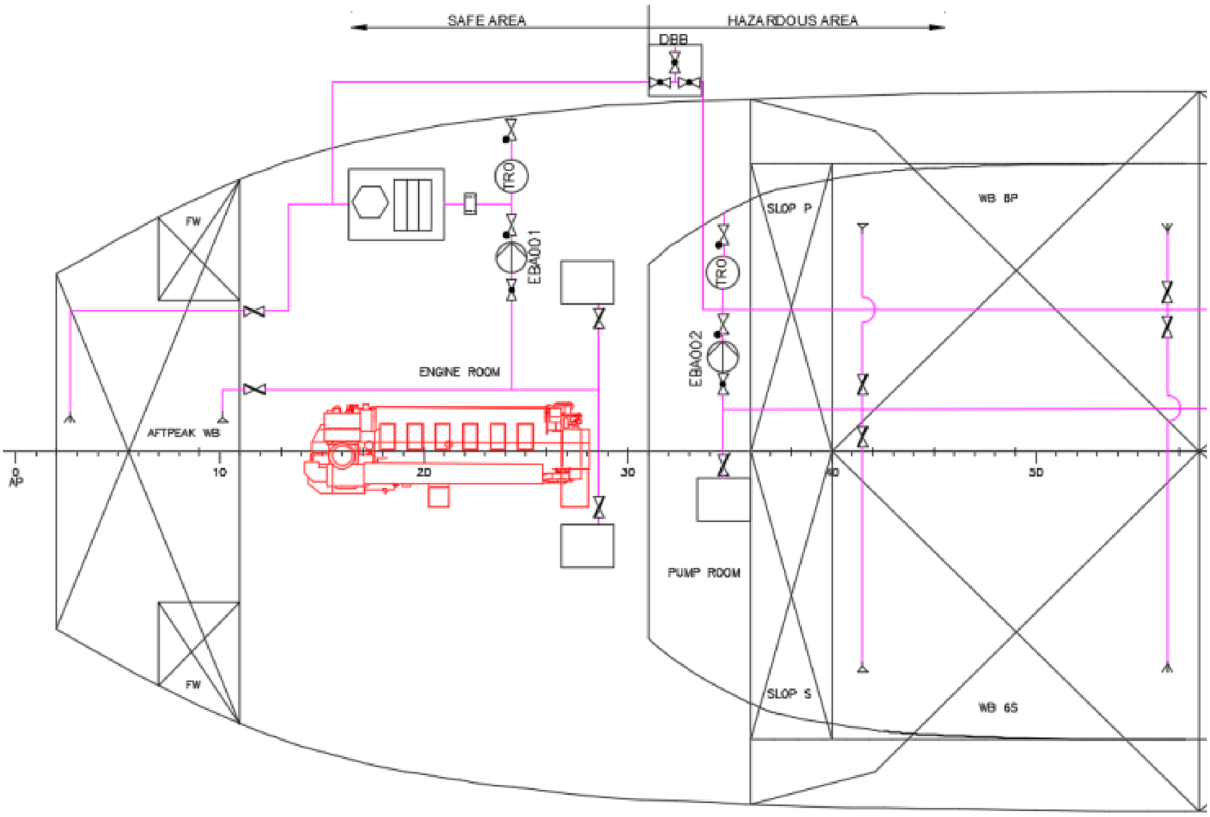

Figure 3- Ballast System with EC type BWTS integrated

For both solution types, an understanding of what else the general service pump is serving will be needed. If the pump is serving as a fire pump, deck wash pump and/or an emergency bilge pump then procedures will need to be put in place to ensure that these non-ballast water mediums are never directed through the BWTS. This is particularly important for the UV + filtration solution when considering bilge water which may contain oil. Any oil on the UV lamp may create a hotspot with the potential for fire. If practical, an obvious solution for this would be to decouple these other systems to ensure contamination cannot occur (e.g. retain the general service pump as is for serving the firemain and emergency bilge and fitting new ballast pump(s) to serve the ballast system). For the EC based BWTS this may remove the need for a 2-speed pump.

3. Multi-Criteria Analysis

3.1. Methodology

Multi-Criteria Analysis can be described as a structured approach to determine overall preferences among alternative options, where the options strive to accomplish several key requirements (i.e. the criterion). It enables decision makers to look at complex problems that are characterised by both monetary and non-monetary factors, break the problem down into manageable pieces of information, and facilitate well informed decisions (Ref 4).

3.2. Process

A spreadsheet-based tool has been generated to record and determine overall scores for each equipment. The M-CA process applied within the spreadsheet-based tool is described as follows:

a) Each BWTS equipment is assessed against each M-CA criterion (e.g. Acquisition Cost, Adherence to Ballast Water Management Convention and Technology Readiness Level, etc) and a category is populated within the spreadsheet based on this assessment;

b) A initial score is assigned within the spreadsheet for each assessed BWTS equipment based on available information on the category;

c) A confidence rating function, which influences the equipment's rating, is provided to measure the accuracy and reliability of information and therefore the perceived confidence in the data. The initial score is then multiplied by the confidence value;

d) A weighting factor, which accounts for the relative importance of each M-CA criterion, is applied to the product of the confidence value and the initial score, to give the overall score for each equipment against each criterion.

3.3. Source Data

Source data, which has been obtained from BWTS equipment manufacturers, is used to inform the M-CA process wherever possible.

3.4. Confidence Rating

An assessment has been made to identify and record the perceived confidence level of data used to support each M-CA criterion assessment.

For example, if an Original Equipment Manufacturer (OEM) has provided a procurement cost for a BWTS unit in a formal document such as a Request for Quotation (RFQ), then the confidence in this data is believed to be high and this would be recorded as such. Alternatively, if the OEM was unable to provide a written record of any adherence to the BWMC and yet they claimed their equipment was compliant, then a lower confidence rating would be recorded. The value assigned to each confidence rating is converted to a multiplication factor in accordance with Table 3 below.

Confidence Rating	Definition	Multiplication Factor
High	Generally, a written record (i.e. certificate, formal correspondence, etc) is available to support the assessment and the assessor's own experience would agree and support the data that has been provided.	1
Medium	Generally, based on the information made available (i.e. verbal correspondence) during the study, the assessor's own experience would tend to agree and support the data that is available.	0.6
Low	Generally, a written record (i.e. certificate, formal correspondence, etc) has not been made available to support the assessment and /or the assessor's own experience would tend to contradict or challenge the data provided.	0.3

Table 3: Confidence Ratings Definitions and Values

3.5. Weighting Factor

A weighting factor between 1 and 0.3 has been incorporated into the tool which allows the user to rank each M-CA criterion.

Each M-CA criterion has been assigned a weighting factor. The weighting factor to be applied has been assessed as suitable by the designer and would be agreed with the Customer (ship owner/operator).

The ranking has been made in terms of those criteria that are more important when selecting a BWTS in this particular instance (i.e. if the criterion 'Whole Life Cost' is deemed the most important selection criteria then this should receive a 1.0 weighting factor. Alternatively, if 'Obsolescence Strategy' is deemed the least important selection criteria then this should receive a 0.3 weighting factor).

3.6. Sensitivity Analysis

A sensitivity analysis has been undertaken to determine the extent to which low or high confidence data affects the final overall scores (See MULTI-CRITERIA ANALYSIS RESULTS later).

4. CRITERIA DEFINITIONS

4.1. Overview

The scoring definitions matched to each criterion assessed during this study are provided and explained within this section of the report.

4.2. Whole Life Costs

Whole life costs have been estimated by assessing each of the costs associated with the life of a piece of equipment. These costs range from initial procurement costs, installation costs, in-service costs and end of life costs which include equipment disposal costs.

Whole life costs have been broken down into the key elements described in the following paragraphs.

4.2.a. Acquisition Cost

This criterion is defined as the actual acquisition cost, including delivery, associated to a single complete equipment set.

Category	Score
<£150K	100
≥£150K & <£180K	80
≥£180K & <£190K	60
≥£190K & <£210K	40
≥£210K & <£240K	20

Table 4 - Acquisition Cost Categories

4.2.b. Installation Cost

This criterion is defined as the estimated OEM support costs incurred as a result of installation, setting to work, Harbour Acceptance Trials (HATS) Sea Acceptance Trials (SATS), until ultimate acceptance into service of the equipment. The costs are based on installation activity being undertaken during a refit period (RP). Cost associated with generating installation documentation (i.e. Alteration and Addition (A&A) Pack) have been excluded.

Category	Score
£0K (included)	100
<£5K	80
≥£5K & <£10K	60
≥£10K & <£15K	40
≥£15K	20

Table 5 - Installation Cost Categories

4.2.c. (In-Service) Consumable Costs (over 24 months)

This criterion is defined as the estimated costs incurred as a result of consumables, (e.g. cleaning agents and routinely replaced filters) to support the equipment on-board over a 24 month period under normal operation. The score is based on information and standard capitation rates given by each supplier.

Category	Score
£0K (included)	100
<£5K	80
≥£5K & <£15K	60
≥£15K & <£25K	40
≥£25K	20

Table 6 - In-Service Consumable Spares Cost Categories

4.2.d. (In-Service) Contractor Maintenance Costs (Spares and Labour)

This criterion is defined as the estimated costs incurred as a result of contractor maintenance activities over a 24 month period during dockside maintenance periods.

Category	Score
<£1K	100
≥£1K & <£5K	80
≥£5K & <£10K	60
≥£10K & <£15K	40
≥£15K	20

Table 7 - In-Service Contractor Maintenance Cost Categories

4.2.e. (In-Service) Disposal of Consumables Costs

This criterion is defined as the estimated costs incurred as a result of disposal of replaced consumables.

Category	Score
<£1K	100
≥£1K & <£3K	80
≥£3K & <£6K	60
≥£6K & <£9K	40
≥£9K	20

Table 8 - In-Service Disposal of Consumables Cost Categories

4.2.f. (End of Life) Disposal Costs

This criterion is defined as the estimated costs incurred as a result of equipment decommissioning and disposal.

Category	Score
<£8K	100
≥£8K & <£12K	80
≥£12K & <£16K	60
≥£16K & <£20K	40
≥£20K	20

Table 9 - Disposal Cost Categories

4.3. Integration Aspects

Aspects associated with the actual integration of each item of equipment into the ship have been estimated. Integration aspects include work in way and the impact on the current compartment layout, services availability, access and removal route issues.

Each of the integration aspects requiring consideration are discussed in the following sections.

4.3.a. Impact on Current Compartment Layout

This criterion is defined as the estimated impact on the current compartment in terms of Work in Way (WIW) as a result of installation of the new BWTS equipment and its associated equipment.

Category	Definition	Score
No Fit	The BWTS equipment is too large in its current form to be fitted to the ship.	0
Significant	Significant WIW activities are required to install the BWTS equipment. For example, generally large bore (≥200mm) pipe work, large equipment (e.g. pumps, large valves, etc) and structure requires repositioning.	33
Medium	Medium WIW activities are required to install the BWTS equipment. For example, generally medium bore (>100mm and <200mm) pipe work, medium sized equipment (e.g. strainers, valves, etc.) and structure requires repositioning.	66
Minor	Minor WIW activities are required to install the BWTS equipment. For example, generally small bore pipe work (≤100mm) and minor equipment (e.g. small valves, filters, etc) requires repositioning.	100

Table 10 - Impact on Current Compartment Categories

4.3.b. Integration of Services

This criterion is defined as the estimated effort to achieve provision of services required for the BWTs, above and beyond those already in place to/from the area proposed for siting the new BWTS equipment.

Category	Definition	Score
Significant	Significant effort is required to provide required services to the BWTS equipment. For example, generally there is no existing provision of services to/from proposed location of BWTS equipment (e.g. long /new pipe runs are required, significant additional pumping requirements to achieve sufficient pressure head, BWTS equipment requires additional services (Freshwater, Low Pressure (LP) air etc.)).	33
Medium	Medium effort is required to provide required services to the BWTS equipment. For example, generally there is an existing provision of services to/from proposed location of BWTS equipment (e.g. minor pipe run modifications required, minimal pumping requirements to achieve sufficient pressure head).	66
Minor	Minimal effort is required to provide required services to the BWTS equipment. For example, generally there is an existing provision of services to/from proposed location of BWTS equipment (e.g. very minor pipe run modifications required, no additional pumping requirements to achieve sufficient pressure head).	100

Table 11 - Integration of Services Categories

4.3.c. Access and Removal Routes

This criterion is defined as the estimated effect on removal and access routes associated with the installation of the BWTS and associated equipment into the ship. Because of the nature of this equipment, the ability to modularise each BWTS affects the likely impact on removal routes. When assessing each BWTS against this criterion it is assumed that the access hatch has a dimension of 1940x1500mm.

Category	Definition	Score
Significant	Assessment suggests significant removal of permanently sited equipment, structures, pipes, cables to move the BWTS equipment from its position of operation to its disembarkation position and vice versa.	33
Medium	Assessment suggests reduced removal requirement for permanently sited equipment, structures, pipes, cables for movement of the BWTS equipment from its position of operation to its disembarkation position and vice versa.	66
Minor	Assessment suggests minimal removal of permanently sited equipment, structures, pipes, cables for movement of the BWTS equipment from its position of operation to its disembarkation position and vice versa.	100

Table 12 - Access and Removal Route Categories

4.4. Compliance with Standards

Aspects associated with compliance and adherence to standards for each equipment have been examined. The criterion and definitions for each of the standards are discussed in the following sections.

4.4.a. Provides required treatment capacity

This criterion was agreed with the Customer and requires the BWTS equipment to treat a capacity of 500m^3/hr of Ballast Water.

Category	Definition	Score
No	The BWTS equipment does not meet the capacity requirement.	0
Yes	The BWTS equipment does meet the capacity requirement.	100

Table 13 - Provision of Required Treatment Capacity

4.4.b. Conformance to IMO BWM B-3

This criterion is defined as the BWTS equipments' conformance to the BWMC Regulation B-3 and whether the OEM holds a valid Certificate of Type Approval. NOTE: due to the potential associated risks involved, equipment that is in the process of gaining type approval has not been considered, even if the process is planned to complete prior to the assumed equipment procurement date.

Category	Definition	Score
No	The BWTS equipment does not hold a valid Certificate of Type Approval.	0
Yes	The BWTS equipment holds a valid Certificate of Type Approval.	100

Table 14 - Conformance to IMO BWM B-3

4.4.c. Operates within specified operating environment limits

This category is defined as the BWTS equipments' stated operating environment limitations against the limits detailed in the Ballast Water Treatment Equipment Specification sent out to the OEMs.

Category	Definition	Score
None	The BWTS equipment does not meet the defined operating environment limits.	0
Partially	The BWTS equipment partially meets the defined operating environment limits.	66
Fully	The BWTS equipment fully meets the defined operating environment limits.	100

Table 15 - Operating Environment Limits Category

4.5. Availability, Reliability and Maintainability (ARM) Aspects

Aspects associated to ARM are assessed for each item of new equipment. ARM aspects assessed include Technology Readiness Level (TRL), market availability and design life aspects amongst others.

The criterion and definitions for each of the ARM aspects assessed are discussed in the following sections.

4.5.a. Technology Readiness Level

This criterion is defined as the estimated TRL that the BWTS equipment has reached at the date of publication of this report. TRLs provide a structured means of measuring and communicating the maturity of technology. Detailed guidance on the application of TRL assessments is provided at Ref 5.

Each BWTS solution has reached a significant level of maturity (i.e. TRL level 5 or above). Consequentially, for the purposes of this study, each BWTS solution is considered to fall within TRL 5 or higher.

Category	Definition	Score
TRL 5	Technology component and/or basic sub-system validation in relevant environment. (i.e. The basic technological components are integrated with realistic supporting elements so that the technology can be tested in a simulated environment. Examples include “high fidelity” laboratory integration of components.	0
TRL 6	Representative model or prototype system, which is well beyond the representation tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology’s demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in a simulated operational environment.	40
TRL 7	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as an aircraft or vehicle. Information to allow suitability assessments is obtained. Examples include testing the prototype in a test bed vehicle.	60
TRL 8	Technology has been proven to work in its final form and under expected conditions. In almost all cases this TRL represents the end of demonstration. Examples include test and evaluation of the system in its intended environment to determine if it meets design specifications, including those related to supportability.	80
TRL 9	Application of this technology in its final form and under ship operational conditions.	100

Table 16 - Technology Readiness Level

4.5.b. Lead Time for Supply of One Ship Set

This criterion is defined as the time period taken to obtain a single ship set of BWTS equipment. The results are based on the information given by the BWTS equipment suppliers at the time of this publication. It is assumed that the BWTS equipment is available in its standard design and no further design activities are required.

Category	Score
< 4 months	100
≥4 months & < 6 months	80
≥6 months & < 8 months	60
≥8 months & < 12 months	40
≥12 months	0

Table 17 - Lead Time Categories

4.5.c. Design Life

This criterion is defined as the anticipated BWTS equipment's design life expectancy. The life expectancies are bound by time periods defined by the suppliers' data given at the time of this publication.

Category	Score
< 1 year	0
≥1 year & <8 years	40
≥8 years & <16 years	60
≥16 years & <25years	80
≥25 years	100

Table 18 - Design Life Categories

4.5.d. In-Service Experience

This criterion is defined as the extent to which the BWTS equipment has entered into operational service on commercial ships at the time of this publication.

Category	Definition	Score
None	The BWTS equipment is not currently in-service on commercial ships.	25
Slight	A limited number (<15) of BWTS equipment are currently in-service on commercial ships.	50
Medium	A limited number (≥15 and <100) of BWTS equipment are currently in-service on commercial ships.	75
High	A significant number (≥100) of BWTS equipment are currently in-service on commercial ships.	100

Table 19 - In-Service Categories

4.5.e. Market Availability

This criterion aims to assess market availability of the BWTS equipment at the time of this publication. The BWTS equipment must be a completed assembly, ready for installation without the requirement for additional development or manufacturing effort from the time of order.

Category	Definition	Score
Yes	The BWTS equipment is immediately available to order as a standard product from the manufacturer. No further work will be required to enable the standard specification BWTS equipment to be fitted to the ship.	100
No	The BWTS equipment is not immediately available to order as a standard product from the manufacturer. Further work will be required to enable the standard specification BWTS equipment to be fitted to the ship.	50

Table 20 - Market Availability Categories

4.5.f. Availability of Documentation (Maintainer/ Operator Manual)

This criterion is defined as the BWTS equipment suppliers' ability to provide documentation relating to operator and maintenance manuals/procedures for the BWTS equipment.

Category	Definition	Score
Yes	Operator and maintenance manuals/procedures are currently available to support the BWTS equipment.	100
No	No documentation relating to operator or maintenance procedures are currently available to support the BWTS equipment.	50

Table 21 - Documentation (Maintainer/ Operator Manual) Categories

4.5.g. Availability of Documentation (Equipment Safety Assessment Documentation)

This criterion is defined as the BWTS equipment suppliers' ability to provide documentation relating to equipment safety assessments for the BWTS equipment.

Category	Definition	Score
Yes	Equipment safety assessments are currently available to support the BWTS equipment.	100
No	No documentation relating to equipment safety assessments are currently available for the BWTS equipment.	50

Table 22 - Documentation (Equipment Safety Assessment Documentation) Categories

4.6. BWTS suppliers' Company Capabilities

Aspects associated to each BWTS suppliers' Company capability are assessed for each BWTS. The criterion and definitions for Company pedigree are discussed in the following sections.

4.6.a. Company Reputation

The criterion is defined as the companies' track record with respect to their experience in supplying equipment to the marine industry.

Category	Definition	Score
No Experience	The company has no experience of supplying equipment to the marine industry.	0
Little Experience	The company has little experience of supplying equipment to the marine industry. They may have supplied quotations in the past or low numbers of equipment (less than ten units).	33
Moderate Experience	The company has some experience in supplying equipment (less than one hundred units) to the marine industry.	66
Significant Experience	The company has significant experience in supplying a large number of equipment (greater than one hundred units) to the marine industry.	100

Table 23 - Company Reputation

4.6.b. Company ISO Accreditation

The criterion is defined as the state of the company's ISO accreditation, either ISO 9001 certification or the more recent ISO 9001:2000 standard.

Category	Definition	Score
Not Accredited	The Company is not accredited to ISO 9001 or ISO 9001:2000.	0
Accredited ISO 9001	The Company is accredited to ISO 9001.	50
Accredited ISO 9001:2000	The Company is accredited to ISO 9001:2000.	100

Table 24 - ISO Accreditation

MULTI-CRITERIA ANALYSIS RESULTS

Category	UV1	UV2	EC1	Weighting
Equipment Whole Life Costs				
(Acquisition) Supply and Delivery of One BWTS	40	80	100	1
(Installation) Installing the Equipment, Setting to Work, HATS and SATS	14	24	36	0.6
(In-Service) Consumable Spares Costs (over 24 months)	18	30	30	0.3
(In-Service) Contractor Maintenance Costs (Spares and Labour) (over 24 months)	7	12	7	0.3
(In-Service) Disposal of Consumables (Filters/Lamps etc)	30	30	30	0.5
(Disposal) System Decommissioning/Disposal Costs	6	6	6	0.1
Sub Total	**116**	**182**	**209**	
Ranking	**3**	**2**	**1**	
Integration Aspects				
Impact on Current Compartment Layout	33	33	33	1
Integration of Services	66	66	33	1
Entry and Removal Routes	60	60	40	0.6
Sub Total	**159**	**159**	**106**	
Ranking	**1**	**1**	**3**	
Compliancy with Standards				
Provides Required Treatment Capacity (500 cums/hr)	100	100	100	1
Treatment Conforms to IMO BWM B-3/SOLAS (see note 1)	100	100	100	1
Operates within Specified Operating Environment Limits (see note 2)	40	60	60	0.6
Sub Total	**240**	**260**	**260**	
Ranking	**3**	**1**	**1**	
Availability, Reliability and Maintainability Aspects				
Technology Readiness Level	100	100	100	1
Lead Time (Months)	30	30	24	0.3
Design Life (Years)	36	60	36	0.6
In-Service Experience	30	23	23	0.3
Market Availability	30	30	30	0.3
Availability of Documentation (Maintainer/Operator Manual)	30	30	30	0.3
Availability of Documentation (Equipment Safety Assessment Documentation)	30	30	30	0.3
Handover Training Provided	80	80	80	0.8
Sub Total	**366**	**383**	**353**	
Ranking	**2**	**1**	**3**	
Company Capability				
Company Reputation	30	10	30	0.3
Company ISO Accreditation	30	30	30	0.3
Sub Total	**60**	**40**	**60**	
Ranking	**1**	**3**	**1**	
Overall Total	**940**	**1023**	**987**	
Overall Ranking	**3**	**1**	**2**	

	Ranking Summary		
Category	UV1	UV2	EC1
Equipment Whole Life Costs	116	182	209
Integration Aspects	159	159	106
Compliancy with Standards	240	260	260
Availability, Reliability and Maintainability Aspects	366	383	353
Company Capability	60	40	60
Overall Total	**940**	**1023**	**987**
Overall Ranking	**3**	**1**	**2**

Figure 4 – M-CA Summary of Results – Prior to Sensitivity Analysis

When reviewing the results of the M-CA based on what was known of the systems and the various challenges involved with each, the results came as somewhat of a surprise: It was believed that the EC BWTS would have ran UV2 a lot closer than was the reality. The fact that UV1 came last was less of a surprise: this system had quite a prohibitive cost (both acquisition and through life) which meant it was on the back foot from the start of the analysis.

Whenever running a M-CA exercise, it is always good to conduct a sensitivity analysis and to double check all entries. Ideally the sensitivity analysis should be conducted with the shipowner/operator to show them the impact of their weightings – they may have second thoughts on what is and isn't important to them when they see the impact it has on a major procurement decision.

For this particular M-CA, it was noted that the scores for integration aspects and for ARM seemed to be the biggest factors in the difference in scores between the UV2 and EC solutions. In particular, two elements drove down the score of the EC system:

- The scores for impact on current compartment layout and for entry and removal routes;
- The confidence in the information provided for design life for the EC system.

With respect to integration aspects scores, these were simply revisited and, on reflection, the difference between the EC solution and both the UV solutions had been incorrectly scored: whilst the additional impact outside of the compartments was worse for the EC solution (routing of pipework up and over the cargo deck), the need to integrate a full Ex rated treatment plant in the already congested cargo pump room for the two UV solutions was considered worse (whilst achievable). Similarly, additional entry and removal routes for the cargo pump room were only needed for the UV solutions and thus the EC system should have scored higher in this area.

With respect to the confidence of information provided for the EC system design life, initially the manufacturer had not provided firm information on this aspect and thus confidence had been marked down. Upon chasing the manufacturer, they provided more firm assurance to back up the claimed 25+ years design life and thus the confidence score was increased to match that of the UV2 solution.

The result of these changes swung the analysis back in favour of the EC solution as can be seen in Figure 5.

Category	UV1	UV2	EC1	Weighting
Equipment Whole Life Costs				
(Acquisition) Supply and Delivery of One BWTS	40	80	100	1
(Installation) Installing the Equipment, Setting to Work, HATS and SATS	14	24	36	0.6
(In-Service) Consumable Spares Costs (over 24 months)	18	30	30	0.3
(In-Service) Contractor Maintenance Costs (Spares and Labour) (over 24 months)	7	12	7	0.3
(In-Service) Disposal of Consumables (Filters/Lamps etc)	30	30	30	0.5
(Disposal) System Decommissioning/Disposal Costs	6	6	6	0.1
Sub Total	**116**	**182**	**209**	
Ranking	**3**	**2**	**1**	
Integration Aspects				
Impact on Current Compartment Layout	33	33	66	1
Integration of Services	66	66	33	1
Entry and Removal Routes	40	40	60	0.6
Sub Total	**139**	**139**	**159**	
Ranking	**2**	**2**	**1**	
Compliancy with Standards				
Provides Required Treatment Capacity (500 cums/hr)	100	100	100	1
Treatment Conforms to IMO BWM B-3/SOLAS (see note 1)	100	100	100	1
Operates within Specified Operating Environment Limits (see note 2)	40	60	60	0.6
Sub Total	**240**	**260**	**260**	
Ranking	**3**	**1**	**1**	
Availability, Reliability and Maintainability Aspects				
Technology Readiness Level	100	100	100	1
Lead Time (Months)	30	30	24	0.3
Design Life (Years)	36	60	60	0.6
In-Service Experience	30	23	23	0.3
Market Availability	30	30	30	0.3
Availability of Documentation (Maintainer/Operator Manual)	30	30	30	0.3
Availability of Documentation (Equipment Safety Assessment Documentation)	30	30	30	0.3
Handover Training Provided	80	80	80	0.8
Sub Total	**366**	**383**	**377**	
Ranking	**3**	**1**	**2**	
Company Capability				
Company Reputation	30	10	30	0.3
Company ISO Accreditation	30	30	30	0.3
Sub Total	**60**	**40**	**60**	
Ranking	**1**	**3**	**1**	
Overall Total	**920**	**1003**	**1065**	
Overall Ranking	**3**	**2**	**1**	

	Ranking Summary		
Category	UV1	UV2	EC1
Equipment Whole Life Costs	116	182	209
Integration Aspects	139	139	159
Compliancy with Standards	240	260	260
Availability, Reliability and Maintainability Aspects	366	383	377
Company Capability	60	40	60
Overall Total	**920**	**1003**	**1065**
Overall Ranking	**3**	**2**	**1**

Figure 5 - M-CA Summary of Results – Post Sensitivity Analysis

5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, it can be seen that selection of a suitable Ballast Water Treatment solution for a particular ship requirement may not be as cut and dried as it first appears. The variables to be considered are many and extend beyond the obvious price and fit considerations.

Many of the variables to be considered require a subjective approach when determining the scores for each criteria which can open up the assessment to bias (conscious or otherwise). Seemingly minor changes in owner preferences and/or data confidence can mean the answer may change and it is important therefore that the first answer reached is thoroughly interrogated; ideally with the Customer involved, to ensure that the best solution is chosen. These facts highlight the need for all important variables to be thoroughly assessed and for sensitivity analyses to be undertaken in order to reach a robust answer that can be confidently presented to the customer.

In many cases, whilst conducting a thorough and fair M-CA analysis may indeed result in an appropriate recommendation for the most suitable solution for a specific vessel (or vessel type), in reality customer preference will often take precedence.

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7. REFERENCES

1 International Maritime Organization (2004), International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention).

2 Code of Federal Regulation (CFR), Title 46: Engineering, Part 162 – Engineering Equipment, Subpart 162.060—Ballast Water Management Systems, November 2018.

3 Code of Federal Regulation (CFR), Title 33: Navigation and Navigable Waters, Part PART 151—Vessels Carrying Oil, Noxious Liquid Substances, Garbage, Municipal Or Commercial Waste, And Ballast Water, Subpart C—Ballast Water Management for Control of Nonindigenous Species in the Great Lakes and Hudson River and Subpart D—Ballast Water Management for Control of Nonindigenous Species in Waters of the United States, November 2018.

4 Michael Spackman et al., Multi Criteria Analysis Manual, 2000.

5 AMS Guidance Document on Technology Readiness Levels, FBG/36/10, 4th February 2002.