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# Design Evaluation Methodology for Ships' Outfitting Equipment by Applying Multi-criteria Analysis: Proper Choices Analysis of Ballast Water Management Systems

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**Abstract.** All ocean-going ships must be outfitted with adequate ballast water equipment in compliance with Regulation D-2, Section D, Standards for Ballast Water Management, International Convention for the Control and Management of Ships' Ballast Water and Sediments, promoted by the International Maritime Organization. However, it is difficult to choose the appropriate equipment because the methods used to develop the equipment have similar advantages and disadvantages . Such circumstances make it difficult for two parties who have conflicting priorities, ship designers and ship owners, to choose the most suitable equipment. To address this issue, multi-criteria analysis is effective because it can simultaneously consider several criteria under evaluation as early as possible in the design stage. The aim of this paper is to propose an evaluation methodology for outfitting appropriate ballast water management system (BWMS) equipment by applying multi-criteria analysis combined with the value engineering concept. This combination can directly compare the benefits of function and the disbenefits of cost aspects of a particular system. Nine available methods were evaluated before their installation on ocean-going vessels with a carrying capacity of 300,000 deadweight tons (DWT). The results of the analyses show that, from a ship designer's point of view, the most appropriate method is one that uses ozone; while, from the viewpoint of a ship owner, the most appropriate method is one that uses a combination of a filter and ultraviolet radiation. Ship designers and ship owners have different opinions. A ship designer emphasizes cost reductions and profit maximization. On the other hand, a ship owner prefers to have a ship outfitted with a system that is easy to operate as well as to maintain.

*Keywords:* Ballast water management system; Multi-criteria analysis; Ship outfitting; Value engineering

## 1. Introduction

Ship outfitting, which consists of various types of processes, is one of the most important stages in designing and building a vessel. Outfitting requires equipment that must comply with the International Convention for the Control and Management of Ships' Ballast Water and Sediments promoted by the International Maritime Organization (IMO), which entered into force on September 8, 2017 (IMO, 2004). Ballast water is very important for ensuring the

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seaworthiness of non-fully-laden vessels (NRC, 1996). When a vessel offloads its cargo, its ballast tanks are flooded with seawater for stability. The seawater is then discharged at a particular port when the vessel is reloaded with cargo (see Figure 1). However, ballast water also introduces invasive organisms, which are very dangerous to ocean health (La Carbona et al., 2010).

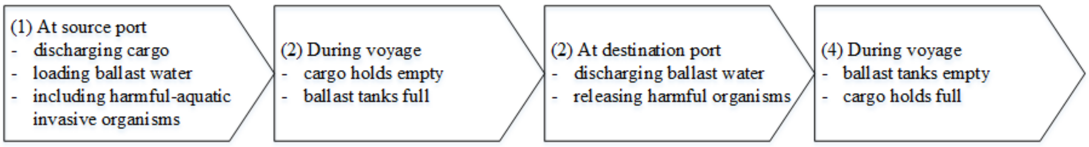



**Figure 1** Ballasting process

A ballast water treatment system must be selected at an early stage of ship design because it influences the layout of the machinery space and increases capital cost. Each treatment method sometimes performs similarly, making it difficult for both ship owners and ship designers to choose the most appropriate equipment. To address this issue, multi-criteria analysis is effective because it can simultaneously consider several qualitative criteria under evaluation as early as possible in the design stage. However, conventional multi-criteria analysis usually ranks criteria without considering the degree of appropriateness of the results. And yet, it is important to consider the degree of appropriateness as doing so yields clear insights that can reduce the gap between the opinions of ship owners and ship designers. Thus, the aim of this paper is to propose an evaluation methodology for outfitting ut appropriate ballast water management equipment by applying multi-criteria analysis combined with a value engineering concept. The value engineering concept will be introduced in the evaluation methodology because it is considered the benefits of function aspect and disbenefits of cost aspects The evaluation based on the views of ship owners and ship designers/shipyard was conducted for vessels with a carrying capacity of 300,000 deadweight tons (DWT): very large crude carriers/very large ore carriers. These vessels must comply with Regulation D-2, Annex – Section D, Standards for Ballast Water Management, International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO, 2004).

**Table 1** Ballast Water Management System (BWMS) Method

| Treatment Components | | Treatment Process | Capacity ($m^3$/h) | Neutralization |
|---|---|---|---|---|
| (T1) | Ozone | Ozone injected into ballast tank will kill harmful microorganisms and produce hypobromite as a byproduct. The byproduct will be neutralized when de-ballasting is carried out. | 3,000 | yes |
| (T2) | Filter + Hypochlorite + Cavitation | After filtrating plankton sized 50 mμ or larger, harmful microbes will be exterminated by filling tanks with sodium hypochlorite, agitated by a venture tube. The residual chemical is then neutralized. | 4,500 | yes |
| (T3) | Filter + UV | Microbes resulting from plankton filtration through a disk-filter will be destroyed using UV. | 6,000 | no |
| (T4) | Filter + UV + $TiO_2$ | After filtrating plankton sized 50 mμ or larger, microbes will be killed using UV, supplemented with titanium dioxide. The residual chemical is neutralized when de-ballasting. | 3,000 | yes |

| | | | | |
|---|---|---|---|---|
| (T5) | Filter + $N_2$ gas + Cavitation + Electrolysis | After filtrating plankton sized 50 mμ or larger, microbes are destroyed by sterilization in the cavitation unit using nitrogen gas and electrolysis. | 10,000 | no |
| (T6) | Flocculant + Filter | Microbes are sedimented by filling tanks with flocculant and magnetic powder and are then separated from seawater by a magnetic disc. | 2,400 | yes |
| (T7) | Electrolysis | The microbes are destroyed by sodium hypochlorite and the residual chemical is neutralized. | 300 or more | yes |
| (T8) | Filter + $CO_2$ | After filtrating plankton sized 50 mμ or larger, remaining microbes are killed using chlorine dioxide. | 16,000 | yes |
| (T9) | Filter + Hypochlorite | After filtrating plankton sized 50 mμ or larger, microbes are destroyed using sodium hypochlorite. The residual chemical is then neutralized. | 625 | yes |

## 2. Ballast Water Management System (BWMS)

Various Ballast Water Management System (BWMS) products have been developed and are available in the market to meet Regulation D-2, which specifies the maximum number of viable organisms that can be discharged and prescribes that all new vessels built after September 8, 2017, must conform to the D-2 standard (IMO, 2019). Table 1 shows nine BWMS methods utilized in various types of equipment. Although these methods have been approved and manufactured (Class, 2021), some are still being researched (Li et al., 2014; Moffitt et al., 2015). Most methods shown in this table use multiple processes to adhere to the disinfection standard prescribed in the Convention.

## 3. Methodology

### *3.1. Method for Selecting Appropriate BWMS Equipment*

Since the introduction of the Convention by IMO (2004), a substantial amount of ballast treatment equipment has been developed and produced. Such equipment must meet several criteria described in Regulation D-5.2. Few studies on the evaluation and selection of ballast water treatment systems have been conducted (Kuroshi & Ölçer, 2017). This is despite the fact that such research is very important for ensuring that new vessels not only comply with the Convention but also generate benefits for many stakeholders. Because existing equipment were developed using several criteria, their selection must also be based on these criteria. However, these criteria have complex interrelationship, equipment selection can be difficult. Such circumstances can only be overcome by applying the multi-criteria decision making (MCDM) method.

Although many MCDM methods exist, none of them can be considered the best, depending on certain situations (Polatidis et al., 2006). Moreover, only a few MCDM methods can be used to select the appropriate BWMS equipment. A study conducted by Satir (2014) on a 15,000-DWT Handysize dry bulk carrier (10 years old) and a 120,000-DWT Aframax oil tanker (new building ship) using a generic fuzzy analytic hierarchy process (GF-AHP) only assessed and ranked five technologies. Šateikiene et al. (2015) evaluated seven technologies using PROMETHEE. However, their results only identified the most appropriate equipment without sufficiently analyzing why they were selected. Bakalar (2016) partially analyzed a criterion for determining the appropriateness of BWMS technology—that is, difficulties faced by ship crew while operating a particular technology—using multi-criteria analysis, a questionnaire, a survey, and interviews.

Kuroshi and Ölçer (2017) investigated the viability of ballast water management concepts in consideration of the evaluation criteria stipulated in the 2004 Convention using a MCDM technique known as intuitionistic fuzzy multi-attribute axiomatic design. This study only ranked the four investigated concepts without providing any practical reference for the selection. Karahalios (2017) proposed the use of AHP-TOPSIS to evaluate appropriate ballast water treatment systems based on the point of view of ship operators. The results only ranked six technologies. Ren (2018) developed a generic framework for ranking and grading the technologies used for ballast water treatment and determined their grades. The framework was then used to evaluate four BWMS technologies. Despite ranking these technologies, the study did not provide insights into how to determine which of these technologies should be applied.

All of the aforementioned MCDM studies only discussed the rankings of existing BWMS equipment from the point of view of a single stakeholder or by considering only one aspect, e.g., the ease of operating the equipment. No further discussion was provided about why a particular technology was selected. Thus, a more comprehensive study, one that accounts for the selection of a technology by more than one stakeholder—namely, a ship designer and a ship owner—should be conducted. Additionally, new methods must be able to yield practical insights or provide references concerning the selection of appropriate equipment.

In this study, a method was employed for selecting appropriate BWMS equipment based on an analytical process of evaluation and decision making concerning uncertainty and complex problems (Shinoda & Fukuchi, 1992; Buana & Shinoda, 2014). This analytical process comprises three stages: (1) constructing a structural evaluation model, (2) defining the grading analysis, and (3) determining an evaluation-decision model.

When constructing a structural evaluation model, all possibly related important factors and necessary items must be collected. The constructed model must also consist of three steps: (i) developing a hierarchy analysis model, (ii) determining items required for independent evaluation, and (iii) calculating the weight of items under evaluation. In calculating the weight of each item, it is important to carefully consider the consistency of the overall calculation.

The grading analysis in the second stage is conducted to estimate the "grade" of objectives regarding a particular item by estimating the effects of the objectives using a sensory scale like "good," "bad," and "excellent." All grades are then used to construct a matrix called an impact matrix, ***P***, as shown by Equation 1. This matrix has an element, $p_{ij}$, which is a grading estimation of the $i$-th object ($1 \leq i \leq$ n) about the the $j$-th item ($1 \leq j \leq$ m).

$$\boldsymbol{P} = \begin{bmatrix} p_{ij} & \cdots & p_{im} \\ \vdots & \ddots & \vdots \\ p_{nj} & \cdots & p_{nm} \end{bmatrix} \tag{1}$$

After that, the degree of advantage between the alternatives under evaluation must be determined using the Concordance Index and the Concordance Dominance Index. The Concordance Index, $c_{ii'}$, is the degree of advance between the $i$-th and the $i'$-th objects, and it is estimated using Equation 2.

$$c_{ii'} = \sum_{j \in R_{ii'}} w_j \frac{|p_{ij} - p_{i'j}|}{\max\limits_{1 \leq i, i' \leq n} |p_{ij} - p_{i'j}|} \tag{2}$$

where $w_j$ is the weight of item $j$, and $p_{ij}$ and $p_{i'j}$ are the grading estimation of the $j$-th item as denoted in matrix ***P***. $j \in R_{ii'}$ is a set of preference conditions, as expressed by Equation 3.

$$R_{ii'} = \{ j | p_{ij} \succ p_{i'j} \} \tag{3}$$

The last stage involves obtaining the total evaluation index, called the Concordance Dominance Index, $c_i$. This index reveals the degree of appropriateness of a particular system under evaluation. Such circumstances can be measured by paying attention to factors affecting the performance of the system. In this study, function and related cost aspects were used to measure the benefits from both aspects by introducing them to the value engineering concept. Value engineering is a systematic process of evaluating a product(s) by considering or combining several aspects concerning functional value as well as the consequences/costs of acquiring the product(s)t. The objective of the process is to determine whether the product is worth implementing. The product can be either completely new (Berawi et al., 2015a; Berawi et al., 2015b) or an improved version (Firmawan et al., 2012). Several studies were conducted to combine the value engineering concept with several multi-criteria analyses. This is because multi-criteria analysis can be used as an evaluation tool to obtain the value of a certain aspect, particularly when dealing with qualitative measurements (Marzouk, 2011; Yan & Qiu, 2011; Montasaera & Montaserb, 2017; Wao, 2018). The value engineering concept has been widely used since the late 1950s for reducing costs during the design stage and is conducted before the construction phase (Panneerselvam, 2012). In this study, the concept was applied before the installation of BWMS equipment.

The most challenging part of value engineering is quantifying aspects, i.e., function and cost, that will be used for evaluating the appropriateness of particular equipment. Multi-criteria analysis can effectively provide a reasonable value of an aspect under evaluation. Therefore, the results of value engineering based on multi-criteria analysis can provide a clear understanding for the ship designer and the ship owner. The ratios can be quickly referenced to decide which ballast water management equipment should be selected. Those related to function aspects were used to obtain the Concordance Index, $c_{i'i}$, while those related to cost items were calculated to determine the Discordance Index, $c_{ii'}$. Both were then compared to obtain the total index as expressed by Equation 4.

$$c_i = \frac{F_i}{C_i} = \frac{c_{ii'}}{c_{i'i}} \tag{4}$$

**Table 2** Evaluation Items for Selecting Appropriate BWMS

| Function Items | Note/Criteria |
|---|---|
| (F1) Capacity | ▪ Treatment performance of ballast pumps<br>▪ High, if the capacity of the system is high |
| (F2) Environmental protection | ▪ Impact on marine pollution after the treatment process for harmful microorganisms<br>▪ High, if the byproduct resulting from the process in the system has a less harmful impact on the environment |
| (F3) Ease of arrangement | ▪ Ease of arrangement on board during ship building<br>▪ High, if the system can be easily arranged on board a particular vessel |
| (F4) User-friendliness | ▪ Ease of system operation<br>▪ High, if the system is easy to operate |
| (F5) Safety | ▪ Concerns health hazards involved in the treatment of chemicals and devices<br>▪ High, if the system is extremely safe when operated |
| (F6) Power consumption | ▪ Impact on total power consumption of the ship<br>▪ High, if the system consumes a low amount of energy |
| **Cost Items** | **Note/Criteria** |
| (1) Initial costs | |
| (IC1) Price | ▪ Price of a particular system<br>▪ High, if the price of the system is low |
| (IC2) Design | ▪ Design cost of applying the system to a ship<br>▪ High, if the cost of designing the layout required by the system is low |
| (IC3) Work | ▪ Cost of installing the equipment on board a ship<br>▪ High, if the cost of the construction and installation of the system is low |
| (IC4) Procurement | ▪ Total cost of negotiations with the supplier, deliverer of the equipment, etc., concerning procurement |

| | |
|---|---|
| (IC5) Commissioning | ▪ High, if the procurement cost is low<br>▪ Cost incurred from the completion of system installation until delivery<br>▪ High, if the commissioning cost is low |
| (2) Running costs | |
| (RC1) Maintenance | ▪ Cost for maintenance and operation after delivery<br>▪ High, if the maintenance cost is low |
| (RC2) Consumable supply | ▪ Total cost of procuring consumable supplies, such as treatment chemicals<br>▪ High, if the cost required by the system for acquiring and keeping needed consumables is low |

### *3.2. Evaluation Items for Selecting Appropriate BWMS Method*

Items used in the evaluation can be grouped into the function aspect and the cost aspect. The function aspect consists of six items, while the cost aspect can be further split into two groups: initial cost and running cost. The function aspect relates to the technical elements required by the BWMS before it is installed on board a particular vessel until it is put into operation. The cost aspect relates to all expenses required to acquire and install the BWMS and to purchase consumables for a specific BWMS. All aspects are selected based on the common experiences of ship designers and ship owners regarding factors that can influence the process of acquiring a particular system—in this case, ballast water management equipment. Thus, the acquirement is conducted before the equipment is installed. The function and cost aspects represent the whole process of acquiring the equipment (Shinoda & Yano, 2012). Table 2 shows all items and the corresponding criteria used in the evaluation.

### *3.3. Weighing Items for Evaluating BWMS*

Before conducting the evaluation for selecting the appropriate BWMS method, it is necessary to calculate the weight of each item. Item weight reflects the degree of importance of a particular item among the whole set of items. In this study, weighing was carried out by using a pairwise concept developed by Saaty (1990). Standard values, ranging from 1 to 5, were used to compare one item with the others. The process began by comparing—and then valuing—one item with the other items. Table 3 shows the results of the pairwise value for function items based on the points of view of the ship designer and ship owner. After determining their values, the weights of items, $w_i$, was calculated by using a geometric mean, $G_i$ (Fukuda et al., 1995). The weight of item $i$, $w_i$, was then normalized. In order to ensure that the calculation of item weight was consistent and satisfactory, a Consistency Index ($CI$) must be calculated, the result of which must be less than 0.1. The $CI$ in the present research was calculated using Equation 5.

$$CI = \frac{\bar{n}-n}{n-1} \tag{5}$$

where $\bar{n} = \frac{1}{n}\sum_{i=1}^{n} n_i$ and $n_i = \frac{\sum_{j=1}^{n}(a_{ij}w_j)}{w_i}$, $i, j = 1, 2, \ldots, n$.

**Table** 3 Pair Test for Function Items

| $a_{ij}$ | | (1) | (2) | (3) | (4) | (5) | (6) | $G_i$ | $w_i$ |
|---|---|---|---|---|---|---|---|---|---|
| (1) Capacity | D | 1 | 2 | 2 | 5 | 1 | 1 | 1.648 | 0.233 |
| | O | 1 | 1/2 | 3 | 4 | 1/3 | 2 | 1.260 | 0.173 |
| (2) Impact on environment | D | 1/2 | 1 | 1/3 | 2 | 1/2 | 1/3 | 0.618 | 0.087 |
| | O | 2 | 1 | 5 | 2 | 1 | 2 | 1.849 | 0.254 |
| (3) Ease of arrangement | D | 1/2 | 3 | 1 | 4 | 1/2 | 1/2 | 1.070 | 0.151 |
| | O | 1/3 | 0.2 | 1 | 1/4 | 1/5 | 1/2 | 0.344 | 0.047 |
| (4) User-friendliness | D | 1/5 | 1/2 | 1/4 | 1 | 1/5 | 1/5 | 0.316 | 0.045 |
| | O | 1/4 | 1/2 | 4 | 1 | 1/3 | 1/2 | 0.661 | 0.091 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (5) Safety | D | 1 | 2 | 2 | 5 | 1 | 2 | 1.849 | 0.262 |
| | O | 3 | 1 | 5 | 3 | 1 | 4 | 2.376 | 0.326 |
| (6) Energy consumption | D | 1 | 3 | 2 | 5 | 1/2 | 1 | 1.570 | 0.222 |
| | O | 1/2 | 1/2 | 2 | 2 | 1/4 | 1 | 0.794 | 0.109 |
| | | | $\Sigma G_i$ | Ship designer | | | | 7.071 | |
| | | | | Ship owner | | | | 7.284 | |
| | | | $CI$ | Ship designer | | | | 0.038 | |
| | | | | Ship owner | | | | 0.050 | |
| Remarks | (1), (2), (3), (4), (5), (6), (7): evaluation items<br>D = ship designer, O = ship owner | | | | | | | | |

The *CI*s, from the point of view of the ship designer, were 0.038 for function aspects and 0.063 for initial cost aspects. This means that the pair test values obtained from the processes concerning function aspects and initial cost aspects were satisfactory.

### *3.4. Goodness Gradation for Evaluation*

After constructing the hierarchy analysis model, all nine selected BWMS methods, as briefly described in Table 1, were evaluated using a set of goodness gradation values. The gradation value is a sensory scale representing the quality of a particular method with regard to an item. The scales are excellent, good, fair, bad, and very bad. The goodness gradation value is made based on ship designer and ship owner opinions. The judgment refers to the criteria also provided by Table 1.

Regarding one function aspect item, "Capacity," four BWMS methods using "Ozone," "Filter + Hypochlorite + Cavitation," "Filter + UV," and "Filter + $N_2$ gas + Cavitation + Electrolysis," have a large capacity. Thus, they are considered "good." One, which uses "Filter + UV + $TiO_2$," has an average capacity; as a result, it is valued "fair." Two methods were judged to be very extreme because of their performance: "Filter + $CO_2$" was "excellent" because it is able to process enormous quantities of ballast water; while, on the other hand, "Filter + Hypochlorite" was "very bad." Two others were slightly better, and were as such scored "bad." Table 4 shows the overall goodness gradation information for the evaluation of function items and will be used to evaluate BWMS methods from the perspectives of ship designers and ship owners.

**Table 4** Goodness Gradation of Function Items

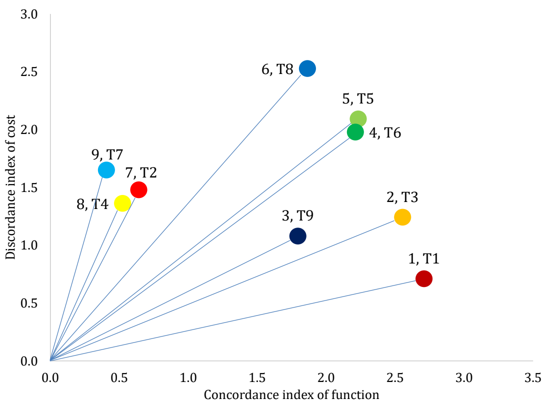
| Function Items | | Capacity | Impact on environment | Ease of arrangement | User-friendliness | Safety | Power Consumption |
|---|---|---|---|---|---|---|---|
| BWMS | (1) Ozone | G | F | F | G | G | F |
| | (2) Filter + Hypochlorite + Cavitation | G | G | Vb | B | F | B |
| | (3) Filter + UV | G | G | G | B | G | B |
| | (4) Filter + UV + $TiO_2$ | F | F | F | F | F | B |
| | (5) Filter + $N_2$ gas + Cavitation + Electrolysis | G | Ex | B | B | G | B |
| | (6) Flocculant + Filter | B | F | F | F | G | F |
| | (7) Electrolysis | B | F | B | Ex | F | B |
| | (8) Filter + $CO_2$ | Ex | G | F | B | F | F |
| | (9) Filter + Hypochlorite | Vb | B | F | G | F | G |

## 4. Discussion

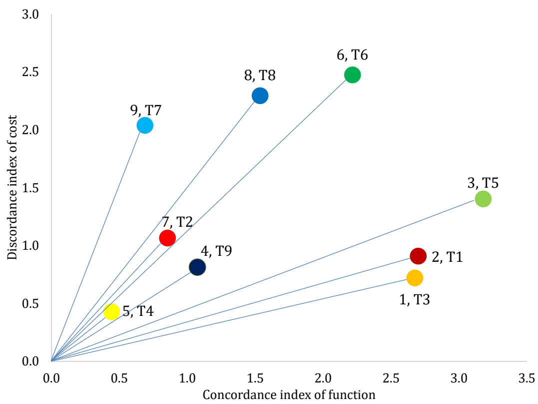
The last stage of the evaluation involves obtaining the value of engineering, which can be used to choose the most appropriate BWMS method. This is carried out by using Equations (2), (3), and (4). In doing so, the goodness gradation values listed in Table 3 must be translated into numerical values. Excellent, good, fair, bad, and very bad are equal to 5, 4, 3, 2, and 1 respectively.

The calculated index, $c_i$, represents the rank of a particular BMWS method from the point of view of either the ship designer or the ship owner. Although the results are significantly different, several methods are the same, i.e., those using "Filter + Hypochlorite + Cavitation" and "Electrolysis." Interestingly, those methods using "Ozone" and "Filter + UV" change alternately. The first is the most appropriate method according to the ship designer; but from ship owner's point of view, it ranks second. The rank of the other method that uses "Filter + Hypochlorite" changes slightly in rank—from third, according to the ship designer, to fourth, according to the ship owner. The ranks of the other four methods shift considerably in two different directions. Those using "Filter + UV + $TiO_2$" and "Filter + $N_2$ gas + Cavitation + Electrolysis" have, according to the ship owner, better performance. On the other hand, the ranks of those methods using "Filter + $CO_2$" and "Filter + Hypochlorite" declined to the sixth and eighth positions, consecutively.

The Value Engineering (VE) index, i.e., $c_i$, which compares the advantage of function items to the disadvantage of cost items, is clearly presented in Figure 2. Here, the degree of appropriateness of a particular BWMS is depicted as the leanness of a line, drawn from the origin point to a particular index, against the horizontal axis. If a line on which an index lies tends to incline toward the horizontal axis, this indicates that a system is more advantageous than disadvantageous. From the ship designer's point of view, as shown in Figure 2 (a), a point denoted by (1), which represents the final calculation index of a method using "Ozone," is considered to be the most appropriate BWMS. This point is on the line with the least slope toward the function axes. Next to this line is (3), which is considered to be the second appropriate method. In summary, the degree of tendency provided by the VE index represents the degree of appropriateness of a particular system. The same circumstances occur in the evaluation based on the ship owner's point of view, as shown in Figure 2 (b).




(a) Ship designer




(b) Ship owner

Remark: legend indicates rank and BWMS

**Figure 2** Distribution of evaluation indices

The main factor that differentiates the results of the evaluation is that the shipyard, i.e., the ship designer, emphasizes cost reductions and the maximization of profit. Therefore, the ship designer has a preference for a particular BWMS, one which is inexpensive, easy to procure, easy to design, and easy to install on a vessel. On the other hand, the ship owner prefers to have a ship outfitted with a system that is easy to operate as well as to maintain. These aspects have nothing to do with those preferred by the shipyard. Thus, these two perspectives need to be reconciled before installing the equipment.

In fact, in the current study, what was ultimately selected for installation on a particular vessel, i.e., very large crude carrier (VLCC), was either "Ozone" or "Filter + Hypochlorite." This is because the location in which the BMWS was to be installed was classified as a hazardous area. In this area, electrical equipment as used in the UV method cannot be selected. These two options, according to the results of the evaluation, are among the four most appropriate methods, particularly "Ozone." The results of the evaluation are summarized in Figure 2 and can also be used as a reference. For example, after omitting "Filter + UV," "Ozone" is the most appropriate selection because it has many more benefits than drawbacks. Thus, it is inevitably the best option. However, the final decision is usually made by the ship owner. If the ship owner were to choose the method that costs the least, then this option would be "Filter + UV."

## 5. Conclusions

An evaluation methodology for outfitting BWMS equipment by applying a multi-criteria analysis method can be constructed and used to select the most appropriate system among the available methods. Each method has several conflicting aspects regarding function and cost. By applying the value engineering concept, these aspects were evaluated with respect to the benefits of function items and the detriments of cost items. The results of the evaluation show the degrees of appropriateness of a particular method. Because the evaluation results from two perspectives, i.e., those of the ship designer and the ship owner, were different, both parties must compromise about which system to install on board an ordered vessel.

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