ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

EVALUATION OF UV AND ELECTROCHEMICAL BALLAST WATER TREATMENT SYSTEMS FROM THE PERSPECTIVE OF EXPERT SEAFARERS WORKING ON THE SHIP

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

UV VE ELEKTROKİMYASAL BALAST SUYU ARITMA SİSTEMLERİNİN GEMİDE ÇALIŞAN UZMAN GEMİADAMLARI AÇISINDAN DEĞERLENDİRİLMESİ

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Mevlüt YILMAZ, a M.Sc. student of ITU Graduate School student ID 508211212 successfully defended the thesis entitled "EVALUATION OF UV AND ELECTROCHEMICAL BALLAST WATER TREATMENT SYSTEMS FROM THE PERSPECTIVE OF EXPERT SEAFARERS WORKING ON THE SHIP'', which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To Ahmet AYMAZ

FOREWORD

I am so thankful to my advisor Asst. Prof. Dr. Ceren BİLGİN GÜNEY for guiding and supporting me.

I would like to thank my dear sons, Ilgaz Ali YILMAZ and Poyraz Ali YILMAZ, who has never stopped supporting me.

I would like to thank my family for giving me support when needed in my whole life.

June 2023 Mevlüt YILMAZ
(Oceangoing Chief Engineer)

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ABBREVIATIONS

AHP	**:** Analytical Hierarchy Process
ANP	**:** Analytic Network Process
BWM	**:** Ballast Water Management
BWMS	**:** Ballast Water Management Systems
BWT	**:** Ballast Water Treatment
BWTS	**:** Ballast Water Treatment System
DWT	**:** Dead Weight Tonnage
EL-CHEM	**:** Electrochemical
IMO	**:** International Maritime Organization
IOPP	**:** International Oil Pollution Prevention Certificate
MACBETH	**:** Measuring Attractiveness by a Categorical Based Evaluation Technique
MAUT	**:** Multi Attribute Utility Theory
MCDA	**:** Multi Criteria Decision Analyses
MEPC	**:** Marine Environment Protection Committee
TOPSIS	**:** Technique for Order of Preference by Similarity to Ideal Solution
TRO	**:** Total Residual Oxidant
UNCED	**:** United Nations Conference on Environment and Development
US	**:** United States
USA	**:** United States of America
USCG	**:** United States Coast Guard
UTA	**:** Utilité Additive
UV	**:** Ultraviolet

SYMBOLS

A	: Pairwise Comparison matrix
b_{ij}	: Element of normalized matrix
B	: Normalization matrix
W	: Priority vector
D	: Weighted sum matrix
E_i	: Value of dividing d_i by w_i
λ	: Consistency check value
CI	: Indicator of Consistency
CR	: Consistency Ratio
RI	: Random Index
n	: Number of criteria
i, j	: Criterion
s_j	: j^{th} option
w_i	: Weight of the i^{th} criterion
p_{ij}	: The weight of the j^{th} option according to the i^{th} criterion

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EVALUATION OF UV AND ELECTROCHEMICAL BALLAST WATER TREATMENT SYSTEMS FROM THE PERSPECTIVE OF EXPERT SEAFARERS WORKING ON THE SHIP

SUMMARY

Ships need ballast water for stability, balance, and safe navigation. Ballast water transported by ships causes the displacement of millions of tons of seawater every year. In displaced seawater, approximately 10,000 living organisms are transported to different ecosystems every day. These transported living organisms can become dangerous and invasive when they can reproduce in the new ecosystem they go to. It is known that these invasive species, which are transported in ballast water and discharged to different ecosystems, cause serious ecological damage, economic losses, and negativities in human health in the marine environment.

In order to prevent these harmful invasive species carried by ballast water, International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted by IMO in February 2004 and entered into force as of 8 September 2017. In the "D" part of this convention, the standards of the ballast water to be discharged into the sea are specified. D1 standard means “Balast water exchange standard” and D2 standard means “Balast water treatment standard”. The D1 standard will expire on 8 September 2024 and from that date all ships will have to meet the D2 standard.

Ships must be equipped with a type-approved ballast water treatment system in order to meet the D2 standard. Nowadays, there are many different producers and methods for ballast water treatment. Generally, UV and electrochemical type BWT system is used on ships.

Within the scope of this study, the features that a BWT system should have were determined. A survey was created because the order of importance of the determined features is different for each seafarer. In the survey created, the seafarers were asked to rate the features in order of importance. According to the survey results, the most important features that seafarers want to have in a BWT system are; The BWT system has few alarms and malfunctions, is easy to maintain and use, and does not contain chemical handling. With the AHP technique based on the real data obtained, a selection was made between the two most used BWTS types on ships. According to the applied AHP method, the UV type BWT system was found to be 1.76 times more preferable than the El-Chem type BWT system.

The maritime company, which has been actively using BWT systems on its ships since 2015, supplied El-Chem type BWT systems to twin tanker ships in 2015, UV-1 brand BWT systems to two different tanker ships of the same tonnage in 2019, and UV-B to two existing tankers of different tonnages in 2021. Equipped 2 brands of BWT systems. According to the applied AHP method, the BWTS type change made by the maritime company in 2019 was seen as positive by expert seafarers.

In order to evaluate the UV-2 brand chosen by the maritime company in 2021, expert seafarers who worked in the UV-1 and UV-2 brands were interviewed. After

evaluating the general opinions of the seafarers who have knowledge and experience in both brands, six different criteria were determined for the application of the AHP technique. The order of importance of the determined criteria has been determined by expert seafarers who have experience in both systems. According to the applied AHP method, the UV-1 brand BWT system was found to be 1.38 times more preferable than the UV-2 brand BWT system. The BWTS brand change made by the maritime company in 2021 was seen negatively by expert seafarers.

In the bilateral meetings with the maritime company, the reasons for choosing the UV-2 brand in 2021 were asked. As the main reason, it was learned that the investment and operating cost of the UV-2 brand is 26% more economical than the UV-1 brand.

If the ship owners act by considering the investment and operating costs in the selection of the BWT system, they may incur more financial losses in the long run because the disruptions that may occur in the ballast operations may directly affect the cargo operations and prevent the ship from staying in the port for too long or the cargo operation.

Until recently, BWTS selection was based on a predetermined set of criteria. With the entry into force of the Ballast Water Management Convention, seafarers have gained sufficient knowledge and experience. With this study, which was implemented in the light of the available data, it was aimed to shed light on the selection of the best BWTS method and manufacturer by taking into account the new criteria determined during the BWTS selection stage.

UV VE ELEKTROKİMYASAL BALAST SUYU ARITMA SİSTEMLERİNİN GEMİDE ÇALIŞAN UZMAN GEMİADAMLARI AÇISINDAN DEĞERLENDİRİLMESİ

ÖZET

Uluslararası nakliyeciliğin %90'ının deniz yolu ile yapıldığı günümüzde gemiler stabilite, denge ve emniyetli seyir için balast suyuna ihtiyaç duymaktadır. Gemiler vasıtasıyla taşınan balast suyu her yıl milyonlarca ton deniz suyunun yer değiştirmesine neden olmaktadır. Yer değiştiren deniz suyu içerisinde her gün yaklaşık 10.000 canlı farklı ekosistemlere taşınmaktadır. Taşınan bu canlılar gittikleri yeni ekosistemde çoğalma şansı bulduklarında tehlikeli ve istilacı bir tür haline gelebilmektedir. Balast suyu içerisinde taşınan ve farklı ekosistemlere boşaltılan bu istilacı türlerin deniz ortamında ciddi ekolojik hasara, ekonomik kayıplara ve insan sağlığında olumsuzluğa neden olduğu bilinmektedir.

Balast suyu ile taşınan bu zararlı istilacı türlerin önüne geçebilmek adına Uluslararası Denizcilik Örgütü (IMO) tarafından 14 Şubat 2004 tarihinde Gemi Balast Sularının ve Sedimanlarının Kontrolü ve Yönetimi Uluslararası Sözleşmesi kabul edilmiştir. Sözleşme gerekli şartların sağlanması sonuçu 8 Eylül 2017 itibari ile yürürlüğe girmiştir. Sözleşmenin ‘’D’’ kısmında denize boşaltılacak balast suyunun standartları belirtilmiştir. D1 standarttı “Balast değişim standardı”, D2 standarttı ise “Balast suyu performans standardı” anlamına gelmektedir. D1 standarttı 8 Eylül 2024 tarihinden itibaren geçerliliğini yitirecektir ve o tarihten itibaren tüm gemiler D2 standardını sağlamak zorunda kalacaktır.

Gemi Balast Sularının ve Sedimanlarının Kontrolü ve Yönetimi Uluslararası Sözleşmesine taraf olan ülkelerin bayrağını taşıyan gemilerin D2 standardını sağlaması için tip onaylı balast suyu ıslah sistemi ile donatılması gerekmektedir. Balast suyu ıslah sistemlerinin kullanılmasıyla birlikte balast suyu içerisinde taşınan zararlı sucul organizmaların farklı ekosistemlere taşınmasıyla oluşan risklerin ortadan kaldırılması hedeflenmektedir. Bu hedef doğrultusunda günümüzde D2 standardını sağlayan balast suyu ıslahı için birçok farklı marka ve tipde balast suyu ıslah sistemi bulunmaktadır.

Balast suyunun arıtılması için temel olarak mekanik, fiziksel ve kimyasal üç farklı yöntem vardır. Genel olarak sistemler iki aşamadan oluşur. Birinci aşamada (ön arıtma), balast suyundaki partiküller ve büyük organizmalar mekanik yöntemlerle tutulur. İkinci aşama, çeşitli fiziksel veya kimyasal yöntemleri veya bunların bir kombinasyonunu içerir. Genellikle gemilerde UV ve elektrokimyasal tip balast suyu ıslah sistemi kullanılmaktadır. Her iki tip balast suyu arıtma sisteminde ön arıtma için mekanik filtre elemanı bulunmaktadır.

Son 5.5 senedir balast suyu arıtma sistemleri yaygın olarak kullanılmaya başlandığından dolayı günümüzde gemi adamları balast suyu arıtma sistemleri hakkında yeterli bilgi ve tecrübe sahibi olmuşlardır. Gemi adamlarının kazandıkları bilgi ve tecrübeler aynı zamanda denizcilik firmalarının balast suyu arıtma sistemleri

hakkında bilgi sahibi olmasını sağlamaktadır. Gemi adamlarının kazandıkları bilgi ve tecrübeden yararlanmak için balast suyu arıtma sistemleri hakkında gemi adamları ile ikili görüşmeler yapılmıştır. Ayrıca filosundaki gemilerinde 2015 yılından itibaren balast suyu arıtma sistemlerini aktif olarak kullanan denizcilik firmasının gemilerinde yaşanan balast suyu arıtma sistemlerine ait arıza raporları incelenmiştir.

Gemilerdeki deneyim eksikliği nedeniyle denizcilik firmaları balast suyu arıtma sistemi seçiminde ekipmanın tip onayına sahip olması, balast suyu karakteristiğine uygun olması, üreticinin güvenirliliği, enerji tüketimi gibi önceden belirlenmiş kriterleri göz önüne almaktaydı.

Bu çalışma kapsamında, bir balast suyu arıtma sisteminin sahip olması gereken özellikler belirlenmiştir. Belirlenen özelliklerin önem sıralamasının her gemi adamı için farklı olmasından kaynaklı bir anket oluşturulmuştur. Oluşturalan ankette gemi adamlarından özellikleri önem sırasına göre puanlaması istenmiştir. Anket sonuçlarına göre gemi adamlarının bir balast suyu arıtma sisteminde sahip olmasını istediği en önemli özellikler; balast suyu arıtma sisteminin az alarm ve arıza yapması, bakım ve kullanımının kolay olması, kimyasal elleçleme içermemesidir. Elde edilen gerçek verilerin temel alınmasıyla oluşturulan AHP tekniğiyle gemilerde en çok kullanılan iki balast suyu arıtma sistemi tipi arasından seçim yapılmıştır. Uygulanan Analitik Hiyerarşi Prosesi (AHP) yöntemine göre UV tipi balast suyu arıtma sistemi El-Chem tipi balast suyu arıtma sistemine göre 1.76 kat daha tercih edilebilir olduğu görülmüştür.

2015 yılından itibaren gemilerinde aktif olarak balast suyu arıtma sistemlerini kullanan denizcilik firması, 2015 yılında ikiz tanker gemilerine El-Chem tipi balast suyu arıtma sistemlerini donatmıştır. 2019 yılında ise aynı tonajdaki farklı iki tanker gemisine UV-1 marka balast suyu arıtma sistemlerini, 2021 yılında ise farklı tonajlardaki mevcut iki tanker gemisine UV-2 marka balast suyu arıtma sistemlerini donatmıştır. Uygulanan AHP yöntemine göre denizcilik firmasının 2019 yılında yapmış olduğu balast suyu arıtma sistem tip değişikliği uzman gemi adamları tarafından olumlu olarak görülmüştür.

Denizcilik firmasının 2021 yılında seçmiş olduğu UV-2 markasının değerlendirilmesi için UV-1 ve UV-2 markasında çalışmış uzman gemi adamları ile görüşülmüştür. Her iki markada bilgi ve tecrübe sahibi olan gemi adamlarının genel görüşleri değerlendirildikten sonra AHP tekniğinin uygulanması için altı farklı kriter belirlenmiştir. Belirlenen kriterlerin önem sıralaması her iki sistemde tecrübe sahibi olan uzman gemi adamları tarafından belirlenmiştir. Uygulanan AHP yöntemine göre UV-1 marka balast suyu arıtma sistemi UV-2 marka balast suyu arıtma sistemine göre 1.38 kat daha tercih edilebilir olduğu görülmüştür. Denizcilik firmasının 2021 yılında yapmış olduğu balast suyu arıtma sistemi marka değişikliği uzman gemi adamları tarafından olumsuz olarak görülmüştür.

Denizcilik firması ile yapılan ikili görüşmelerde 2021 yılında UV-2 marka balast suyu arıtma sisteminin tercih nedenleri sorulmuştur. Ana neden olarak UV-2 marka balast suyu arıtma sisteminin yatırım ve işletim maliyeti UV-1 marka balast suyu arıtma sistemine göre %26 oranında daha ekonomik olduğu öğrenilmiştir.

Gemi sahipleri balast suyu arıtma sistemi seçiminde yatırım ve işletim maliyetlerini düşünerek hareket ederse uzun vadede daha fazla maddi kayba uğrayabilirler çünkü balast operasyonlarında yaşanabilecek aksaklıklar kargo operasyonlarını doğrudan etkileyebilir ve geminin limanda fazla kalmasına neden olabilir.

Yakın zamana kadar balast suyu arıtma sistemi seçimi önceden belirlenmiş bir dizi kritere dayanmaktaydı. Balast Suyu Yönetimi Sözleşmesinin yürürlüğe girmesiyle birlikte gemi adamları yeterli bilgi ve tecrübeye sahip olmuşlardır. Eldeki veriler ışında hayata geçirilen bu çalışma ile birlikte gemi sahiplerinin balast suyu arıtma sistemi seçim aşamasında belirlenen yeni kriterleri göz önüne alarak en iyi balast suyu arıtma sistemi yöntemini ve üreticisini seçmesine ışık tutulmak istenmiştir.

1. INTRODUCTION

Ships use ballast water to maintain their balance and stability, safe navigation, and sufficient seaworthiness in adverse weather conditions during voyages (Endresen et al., 2008). These factors are indispensable in all sea vehicles. Marine vessels need additional weights to provide these factors. In small boats, stability can be achieved with solid, fixed weights, while in larger marine vehicles this is provided with ballast water tanks. Thanks to the ballast water tanks positioned during the shipbuilding phase, the balance of the ships is kept at an optimum level and safe navigation is possible.

Since watercraft have a dynamic structure, the loads on them may vary. In the 20th century, with the production of steel-hulled ships and the advancement of pump engineering, water has become a safer ballast material for ships. Ballast water is necessary to balance and trim vessels by taking seawater into tanks from one place of an international port while cargoes are unloaded and discharging it in the spot of another port while cargoes are loaded (Bailey, 2015). In addition, ballast water is needed to protect the integrity of the ship structure and increase its maneuverability in harsh sea conditions.

The ballast water system, which is one of the most basic things for marine vessels and structures, is of great importance. Ballast water tanks are an integral element of ship design, whatever the type, purpose, structure, and size of the ship. The ballast water carried in these tanks needs to be treated. Because, ballast water is one of the four greatest threats to the world's oceans (David et al., 2018).

There are many living organisms such as plankton, microorganisms, bacteria, and larvae etc. inside untreated ballast water. If ballast water is not treated, these organisms are transported to different ecosystems via ballast water. Ballast water was considered one of the main factors in the spread of invasive species, and prior to the use of BWT systems, approximately 10,000 different organisms was transported to different ecosystems every day via ballast water (Carlton, 1999). The main purpose of the treatment system is to prevent organisms carried in ballast tanks. These organisms transported in ballast tanks pose a potential threat and harm local species living in the areas where they are transported. These species can also cause significant damage to industrial and infrastructure facilities located in coastal areas. In addition to invasive species, many microorganisms harmful to human health can be transported with ballast waters (Kim, Lee, & Seo, 2022). The spread of invasive species carried in untreated ballast water is considered one of the biggest threats to the world ecologically because the damage caused is irreversible (Casas-Monroy & Adams, 2014).

The International Maritime Organization (IMO) adopted the Ballast Water Management Convention (BWM) in 2004 to prevent and reduce harmful aquatic organisms in ballast water (Firestone and Corbett, 2005). As a condition of entry into force of the convention, a period of 12 months has been determined by the IMO after the ratification of 30 countries representing 35% of the world's merchant fleet. After the completion of this process and the fulfillment of the tonnage requirement, the convention entered into force on 08 September 2017 (IMO, 2016a). Turkey became a party to the convention in 2014.

The BWM Convention establishes ballast water management requirements and standards for all types of floating vessels operating at sea, including submersible vessels, offshore support vessels, floating offshore platforms, floating offshore storage units, and other floating marine structures. With this convention, it is aimed to prevent the transportation of marine organisms to different ecosystems. Therefore, it is aimed to minimize or even eliminate the damages caused by untreated ballast waters.

By the BWM Convention, all commercial ships of 400 GT and above flying the flag of the convention states must be equipped with a ballast water treatment system. Marine vessels are required to manage the ballast operation to a certain standard according to the ballast water management plan. There are two ballast water management standards for ships' ballast operation under the BWM Convention. The ballast operation carried out must be carried out by D-1 (Ballast water exchange) and/or D-2 (Ballast water performance) standards (Kuroshi, 2012).

The D-1 standard is a temporary alternative method until the D-2 standards become fully mandatory. According to the BWM Convention, ships were first required to meet D-1 standards for ballast operations. The D-1 standard covers the replacement of ballast water by ships ideally in the open seas 200 nautical miles from land and 200 meters water depth as per the IMO Guidelines. Thus, the potential damage of ballast waters to the local ecosystem will be lower. The BWM convention will be implemented gradually and all international ships are expected to use ballast water management systems (BWMS) rather than ballast water exchange (BWE) to meet convention requirements by 8 September 2024 (Bailey et al., 2022).

For a ship to comply with the D-2 standard, it must have a Ballast Water Treatment System (BWTS) on board. According to the convention, BWTS is obligatory for new commercial ships over 400 GRT to be built. In addition, providing the D-2 standard on existing ships has been made mandatory within the scope of the determined implementation plan. Ships are required to meet D-2 standards by the end of 2023, subject to IOPP (International Oil Pollution Prevention Certificate) renewal surveys.

There are many different ballast water treatment systems available in the maritime market today. Among the existing systems, it is necessary to select and install the appropriate system according to the legal regime that the ship has to comply with. What is important here is not only the flag state to which the ship belongs. In addition, the legal regime of the port area where ballast water will be pumped should be considered. Two main legal regimes exist for BWT systems. The first of these is the regime to be applied in the countries (flag and port administrations) that are party to the IMO convention. The United States of America (USA), on the other hand, is not a party to the IMO convention and has adopted another main legal regime with stricter practices. If a ship belonging to a party country that has adopted the IMO convention is to carry out any ballast operation in USA territorial waters or ports, it must comply with the ballast water management regime applied in the USA. Therefore, when choosing BWT systems, attention should be paid to the legal regime requirements.

While choosing BWT systems, ship owners give priority to the efficiency and cost of the systems. The equipment should have a minimum failure, spare parts should not be expensive, and installation and operating costs should be appropriate. It is also important to select the BWTS suitable for the ship's ballast tank capacity. The ship must quickly fill and unload the ballast tanks in a way that does not disrupt the loading and unloading operations. In an internationally operating ship, the system must have type approval according to the voyage region. The footprint of the BWT system should be suitable for the ship type and size. The capacity of the ballast pump must be sufficient for the treatment unit. In addition, the BWT system must have a worldwide service network and spare parts supply. A fault in the BWT system of a ship sailing internationally needs to be responded to quickly. Because it may disrupt the loading-unloading operation and high fines may be paid by the shipowner to the charterer, the port, and the port state. In addition, different treatment methods are used in ballast water treatment. These treatment methods have advantages and disadvantages compared to each other. The criteria mentioned above should inevitably be taken into account in the system selection. However, these criteria do not include any evaluation of the systems after they are used on the ship, since sufficient experience has not been developed yet. This study was carried out in order to contribute to fill this gap.

For this purpose, the experiences of six BWTS equipped ships belonging to a Turkish Maritime Company were evaluated. First of all, the failure reports of the BWT system were examined and interviews were held with expert seafarers who worked with these systems. Based on the information gathered, a set of criteria for system evaluation was developed and a questionnaire was prepared. The prepared questionnaire was presented to expert sailors. The results of this survey were evaluated by the Analytical Hierarchy Process (AHP) method. In this study, prominent problems in UV and Electrochemical systems, which are the most used BWTS types on ships, have been identified and the systems were evaluated based on the onboard experience of expert seafarers.

1.1 International Regulations for Ballast Water Management

Solid weights were used for ballast purposes in the early days when stability problems started on ships. However, this method was both inefficient and time-consuming. With the advancement of engineering and technology in pump systems, the use of water in the environment of the ship has replaced the use of solid weights to ensure the balance and stability of the ships. Ballast water in ships is the load kept in the ballast tanks of the ships and used to ensure safe ship balance throughout the voyage. It is profitable for ship owners to use minimum ballast water on the ships, but given the stability of the ship, it is necessary to take ballast water to the ships to make safer and more efficient voyages. The ship's captain and the ship's officers determine the ballast operations and timing depending on the conditions. Ballast water capacity varies according to the cargo carrying capacity and type of the ship and is between 25-40% of the average dead weight tonnage (DWT) (Carlton et al., 1995). For example, a crude oil tanker, which has a capacity of 156000 DWT, receives around 62400 metric tons on average when she is not carrying cargo. Such a high rate shows the importance of ballast water for ships. While the ships are unloading their cargo, they can also load ballast water into their tanks simultaneously in order to maintain ships' stability respectively, or vice versa. Figure 1.1 shows the cycle of ships' cargo operations and ballast operations.

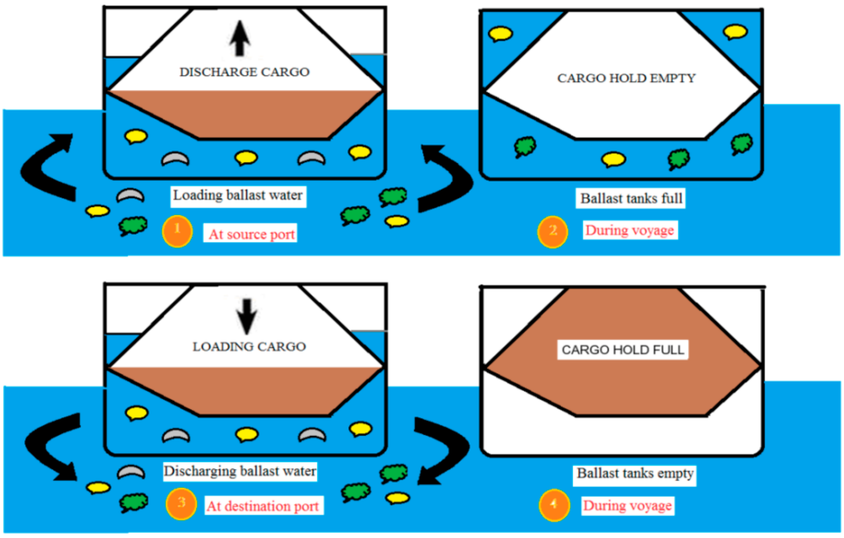

Figure 1.1 : Ballast water cycle (Rata, Gasparotti, & Rusu, 2018).

As a result of the transport of ballast water and sediments by ships, unicellular organisms, small invertebrates, microalgae, spores, seeds, cysts, eggs, larvae, and various kinds of fish are transported to foreign region (Holm et al., 2008; Raaymakers, 2002b). Some of the transported organisms can cause biological invasions in the ecosystem they are involved in. Biological invasion can be defined as the transfer of some species native to different regions to another region, settling in these new regions and changing or disrupting this new region (Olenin et al., 2017). As a result of biological invasion caused by untreated ballast water, health, environmental and economic problems have arisen (Carlton, 2002; Olenin et al., 2000). Solutions were sought and studies were carried out for these problems, which emerged with the involvement of various organizations and port states.

In the late 1980s, Canada and Australia were among the countries in trouble from invasive species. They brought their concerns about invasive species to the attention of the IMO's Marine Environment Protection Committee (MEPC). In 1991 the MEPC adopted the International Guidelines for preventing unwanted organisms and pathogens in ballast water carried on ships. The United Nations Conference on

Environment and Development (UNCED), held in Brazil in 1992, recognized untreated ballast water as a major international concern (Oliveira, 2008). After more than 10 years of complex negotiations between IMO Member States, IMO studied to finalize the BWM Convention, which was adopted at a diplomatic conference in London in February 2004 (IMO, 2004). The BMW Convention entered into force on September 8, 2017, after meeting the number of parties countries, and tonnage requirements (IMO, 2016a). BWM convention consists of two standards for ballast water management. Ballast Water Exchange Standard (D-1 Standard) and Ballast Water Performance Standard (D-2 standard). Even before IMO mandated the BWM Convention, some countries required ships entering their ports to replace their ballast waters offshore. With the implementation plan, ships in the transition period will be able to exchange ballast water in the open seas until 2024 with the D-1 standard (Gollasch & David, 2018). During the transition and follow-up of ships from D-1 standard to D-2 standard, the five-year renewal survey date included in the ship's IOPP certificate is taken as a reference. After 2024, all merchant ships over 400 grt must comply with the D-2 standard, except for exceptions or exempt locations.

To prevent the damages caused by ballast water, the IMO Ballast Water Convention and the United States Coast Guard (USCG) stand out as two legal regimes. The IMO Ballast Water Management Convention is realized under the umbrella of the United Nations and is the convention with the largest area of influence. USCG regulations, on the other hand, include mandatory practices to be carried out in the USA, which is not a party to the IMO Convention.

1.1.1 IMO ballast water management convention

IMO Ballast Water Convention contains twenty-two articles and one annex, which consists of twenty-four technical Regulations, classified in five sections:

- Section A- General Provisions: Covers the applicability conditions, exceptions, and equivalent compliance rules.
- Section B- Management and Control Requirements for Ships: It includes the ballast water management plan, ballast water operation logbook, ballast water management and exchange for the ship, sediment management, and duties of the ship personnel.

- Section C- Special Requirements in Certain Areas: It includes the rules to be considered regarding the purchase of ballast in some special areas, the special precautions of the relevant flag state, and the information exchange provisions.
- Section D- Standards for Ballast Water Management: Includes provisions regarding the ballast water exchange standard, performance standards, validation requirements for ballast water systems, and IMO review of prototype BWTS technologies and standards.
- Section E-Survey and Certification Requirements for Ballast Water Management: In the last section, it contains rules regarding inspection, certification or approval, validity periods of authorized institutions, and documents (Gollasch et al., 2007).

States parties to the convention must comply with the provisions of the convention and its annex. States parties require ships flying their flag or operating under their own administration and participating in the convention to comply with the requirements set out in the convention. The definition of the ship in the Ballast Water Management Convention includes floating production storage and offloading, floating storage units, floating platforms, floating vessels, and any type of vessel operating in the marine environment, including submersible vessels.

Ships not covered by the convention;

- Ships not carrying ballast water
- Ships not operating on international seas
- Warships, auxiliary warships, and other government owned or operated ships
- Ships only on non-commercial service, or
- Ships carrying permanent ballast in sealed tanks (IMO, 2004).

The ship belonging to the country that is not a party to the convention must meet the requirements and conditions related to ballast water management in order to carry out ballast operations at the port of the country that is a party to the convention. 14 guidance documents have been published by IMO for the international implementation of the Convention. With these guides, IMO aims to support and guide ship owners, port authorities, BWTS manufacturers, and classification societies in order to interpret the convention correctly and to provide the necessary technical conditions.

IMO standards

IMO has determined the D-1 and D-2 standards for correct and regular ballast water treatment. The D-1 standard will expire on September 8, 2024 and all ships meeting certain conditions will have to meet the D-2 standards. Figure 1.2 shows the implementation plan of the IMO D-2 standard.

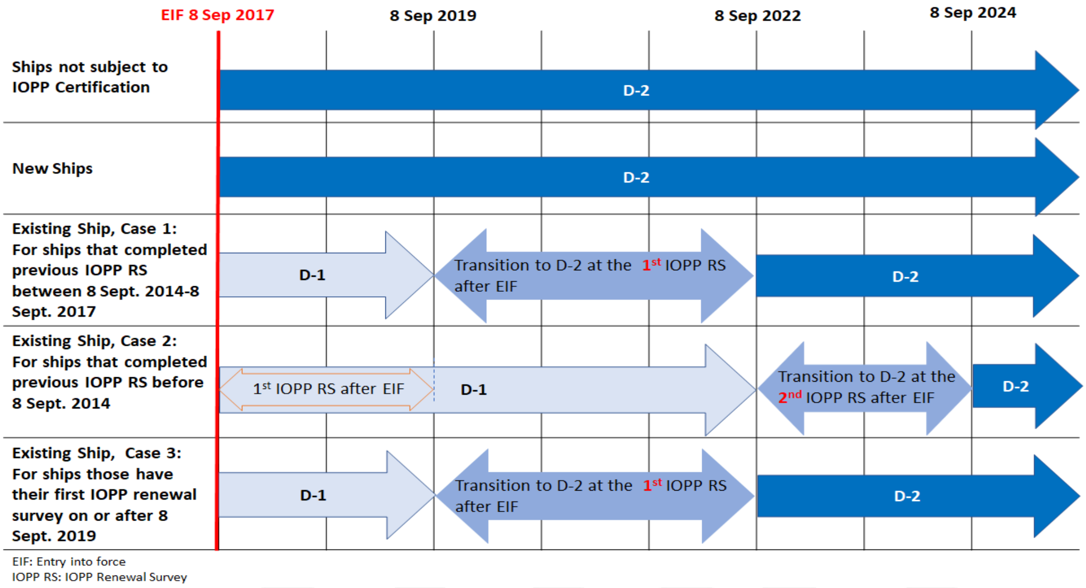

Figure 1.2 : Implementation plan to IMO D-2 standard (Bilgin Güney, 2022).

D-1 standards

The D-1 standard is a standard that covers replacing the ballast water under certain conditions without the need for any equipment. Ballast water exchange method can be defined as the replacement of ballast water taken from the coastal area with open seawater during ballast operation. For ballasting operation, ships suction sea water from sea chest, pass it through a coarse filter, and send it to the tanks thorough by pump or gravity. These sea chests are usually found in the engine room or pump room of ships. In order to discharge the ballast water, the ballast water overboard circuit is used by gravity or a pump. Ballast operations are usually controlled from the cargo room, engine room, or wheelhouse. With the ballast water operation to be carried out in the D-1 standard, a 95% change in the volume of the ballast water is required. For ballast water exchange, an operation should be carried out at least 200 nautical miles from the nearest land and at a depth of at least 200 meters, or if it is not possible to meet these conditions, at least 50 nautical miles from the nearest land, at a depth of at least 200 meters (Tolian, Makhsoosi, & Bushehri, 2020). There are 3 different methods for ships to meet D-1 standards. These methods are sequential method, flow through method, and dilution method, respectively;

- Sequential method: It is applied in the form of discharging the ballast water taken during the port operation in the open sea and filling the tanks with open seawater. After the ballast tanks are emptied, they are refilled with ballast water taken from the open sea to provide at least 95% volumetric change (Herdzik, 2018). In order not to lose the maneuverability of the ship during the ballast water exchange operation, care must be taken to ensure that the propeller is not out of the water. Otherwise, it is possible that the ship's main engine will be damaged due to over speed. With this method, it would be appropriate for the ship's officers who plan to change the ballast water, to do the process over a single tank in order. Ship officers should calculate how long the ballast water change process will take before the operation because it is important for both the working status of the generators and the resting hours of the personnel who will work in the operation.
- Flow through method: It is the method of overflowing the ballast water taken into the ballast tanks by using tank manhole or different devices on the deck of the tank. In order to achieve the 95% change standard required by IMO with this method, three times the volume of the tank should overflow the tank (IMO, 2004).
- Dilution method: It is the process of pumping in the surrounding seawater from the top of the tank while discharging the existing water from bottom of the tank. In this method, in order to meet the 95% replacement requirement, open sea water 3 times the tank capacity must be pumped in and discharged from the tank. If the dilution method is chosen as the ballast water exchange method, the ship's officers should frequently check for changes in tank levels. The amount of seawater added to the tank and the seawater discharged out of the tank should be equivalent. The deck and engine officers should work in coordination in this operation and in an emergency should be able to stop both the pump that floods the tank and the pump that floods the sea from the tank (American Bureau of Shipping, 2010).

D-2 standards

Ships must have a ballast water treatment system in order to perform ballast operations in accordance with the D-2 standard. According to the convention, BWT system to be integrated into ships must have a type approval certificate. The requirements for equipment manufacturers to obtain a type approval certificate are included in the IMO G8 (Guideline for Approval of Ballast Water Management Systems) and G9 (Guide for Approval of Ballast Water Management Systems using Active Substances) guideslines (Bowmer & Linders, 2010).

There are two different approval processes for BWT system to receive type approval. The reason for the difference in the approval processes is that the systems are divided into two as "systems using active substances" and "systems that do not use active substances" according to the contract. Systems that do not use active substances can receive type approval after tests carried out at the land facility and on board. Systems using active substances has a two-stage approval process according to the G9 guideline. In the first stage, it is confirmed with basic approval that there is no harm in using the system in land-based tests. Initial confirmation is based on paper review. In the second stage, the system is subjected to land-based tests and it is documented that the final system will not be harmful to the environment. Table 1.1 shows the ballast water treatment standards of IMO and USCG.

Table 1.1 : Comparison of ballast water discharge standards (Leočampara et al., 2019).

Organism Size	IMO D-2 Standart	USCG Standart
Size ≥50 µm in min dimension	< 10 viable organisms/m^3	< 10 living organisms/m^3
10 ≤ Size < 50 µm in min dimension	< 10 viable organisms/mL	< 10 living organisms/mL
Escherichia coli	< 250 cfu/100 mL	< 250 cfu/100 mL
Intestinal enterococci	< 100 cfu/100 mL	< 100 cfu/100 mL
Toxicogenic Vibrio cholerae	< 1cfu/100mL or < 1cfu/g Zooplankton samples	< 1 cfu/100 mL

1.1.2 USCG ballast water management

In addition to the international standards on ballast water management established by IMO, the US Senate have adopted much stricter practices than the BWM convention. In March 2012, the Coast Guard published the rule "The Standard for Living Organisms in Ship Ballast Waters Discharged in US Waters". The rule entered into force in June 2012 and the Coast Guard has added to this rule and set a standard that determines the allowed organism values in discharged ballast waters. These standards apply to all US flagged or non US flagged vessels entering US waters. Table 1.2 shows the USCG standard implementation dates according to the ballast capacity.

Table 1.2 : USCG standard implementation dates (IRClass, 2018).

Vessels	Vessel's ballast water capacity	Date constructed	Vessel's compliance date
New Vessels	All	On or after December 1, 2013	On delivery
Existinthang Vessels	Less than 1500	Before December 1, 2013	First scheduled drydocking after January 1, 2016
Existinthang Vessels	1500-5000	Before December 1, 2013	First scheduled drydocking after January 1, 2014
Existinthang Vessels	Greater than 5000	Before December 1, 2013	First scheduled drydocking after January 1, 2016

The law, which took effect in June 2012, covers all ships with ballast tanks that enter the 12 mile boundary of the US coastline. Therefore, ballast waters discharged 12 miles from the nearest land are not covered by this law. Within the scope of this law, the USA has set a number of compliance standards for ships carrying ballast. a ship in United States territorial waters;

- Will not discharge ballast; or
- Have a USCG-approved ballast water treatment system; or
- If it does not have a USCG approved ballast water treatment system, it will perform ballast water at facilities operating for ballast water treatment; or
- The ballast water will be met only from the United States city water system (USCG, 2018).

If a ship cannot meet the above conditions, two temporary solutions have been produced to find it in United States territorial waters with ballast water.

- Use a foreign-approved ballast water treatment system that has been inspected and accepted by the USCG; or
- Will request additional time from USCG to meet the required conditions (USCG, 2018).

Ships meeting the following conditions are exempt from this law;

- Non-seagoing vessels;
- Sea-going vessels that do not operate outside EEZ and are less than 1,600 Gross Register Tons or 3,000 ITC; and,
- Vessels that operate exclusively in 1 COTP Zone (USCG, 2018).

1.1.3 Comparison of the IMO BWM and the USCG BWM differences

There are certain differences between the IMO and USCG BWM regulations. IMO BWM has established the international regulations applied in the legislation of the member states that are party to the convention. The USA, on the other hand, is not a party to the convention established by IMO and has developed national BWM legislation applicable to ships operating in its own territorial waters. This legislation developed by the USA is considered more prescriptive and demanding than the legislation created by IMO.

There are differences between the USCG Type Approval Guide and the IMO G8 guide on how to apply and interpret the standards. BWTS type approval is mandatory in the USA and is more tightly regulated and more detailed than the IMO type approval process (Leočampara et al., 2019). During the USCG type approval process, onboard tests are performed by the ship's personnel, not the manufacturer's personnel. There is no information on this subject in the IMO G8 guide. While both standards require a minimum of six months onboard testing, the G8 guideline considers three consecutive successful test cycles sufficient, while the USCG requires five successful test cycles. This is because in independent lab tests some systems fail on the fourth or fifth cycle. The important technical differences between these two arrangements shows in Table 1.3. IMO has developed the G8 and G9 guidelines for BWTS type approval.

Table 1.3 : IMO and USCG BWMS type approval process comparison (Leočampara et al., 2019).

Comparison items	IMO	US
Approval by	Flag or Class (Recognized Organizations (RO))	USCG
Test operator	Manufacturer	IL
Test laboratory	Laboratory not owned/affiliated with manufacturer/vendor of BWMS/major equipment components	United States Coast Guard (USCG) approved IL
Reporting of test results	Manufacturer/Laboratory	IL
Testing methods required	G8/G9 Guidelines	USCG BWMS Environmental Technology Verification (ETV) Protocol
Performance/Discharge standard	<10 viable organisms	<10 living organisms
Shipboard 3 consecutive successful testing cycles	3	5
Minimum holding time in the test tanks before discharge and sampling for the BWMSs not using Active Substances	Minimum holding time to be determined by the BWMS manufacturer (D-2 standard compliance); ≥5 days (regrowth evaluation)	≥1 day; If justified in Test/Quality Assurance Plan, shorter or longer tank hold times may be utilized
Component/Environmental test (vibration endurance test)	2 h	4 h

One of the differences between the IMO and USCG type-approval guidelines is the waiting time. Waiting time refers to the time that the ballast water taken into the tank should stay in the tank at least before discharge and sampling. The purpose of the waiting period is to measure the efficiency of the system on organism reproduction. Usually on ships equipped with BWTS, as it is treated while loading ballast water, if an organism survives, it can reproduce in the tank. The waiting time will show whether the system meets the D-2 standard if this reproduction occurs (USCG, 2017). While this period is 120 hours in the IMO standard shore tests, the USCG has determined this period as 24 hours. Another difference between the two types approval guidelines is component and environment testing. Component and environmental testing include endurance testing of electrical and electronic components to determine the long-term operational performance of BWTS equipment in marine conditions (USCG, 2017). This test is named as environmental test in IMO G8 guideline and as component test in USCG type guide. The main difference in these tests is that the minimum time required for vibration endurance is 2 hours in the IMO guideline and 4 hours in the USCG guideline (Leočampara et al., 2019).

1.2 Ballast Water Treatment Methods

The main aim of ballast water treatment is the removal or inactivation of organisms transported by ballast water. In order to prevent the damages caused by these transported organisms, different treatment methods are used in the systems installed on the ships. There are basically three group of methods for the treatment of ballast water: mechanical, physical, and chemical. Generally, systems consist of two stages. In the first stage (pre-treatment), particles and large organisms in the ballast water are retained by mechanical methods. The second stage involves various physical or chemical methods, or a combination thereof. With each component in the first and second stages of these systems, by aiming different organisms, water is treated and filled into ballast tanks. The treated water can then be discharged to the sea, but in a system where retreatment or neutralization is required, the water must be again treated. Figure 1.3 shows ballast water treatment methods.

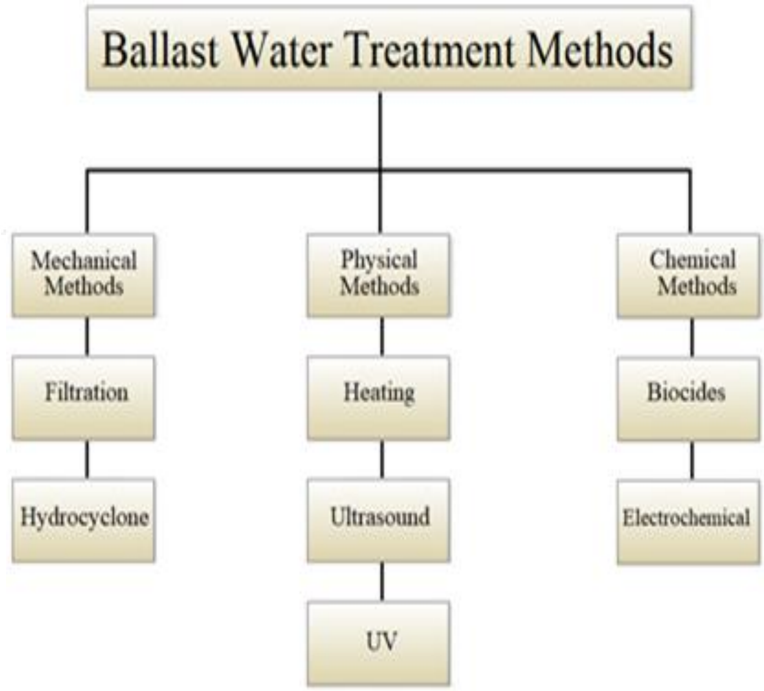

Figure 1.3 : Ballast water treatment methods.

1.2.1 Mechanical methods

Mechanical methods consist of filtration and hydrocyclone methods. Generally, the mechanical methods used in the pre-treatment process are natural separation methods that do not require a chemical or physical reaction. Although they cause a slight decrease in ballast pump capacities, they are easy and economical to install.

1.2.1.1 Filtration

It is an environmentally friendly and high efficiency method used to remove living, microorganism or solid substances in sea water before they are taken into ballast tanks (Sayinli et al., 2022). Generally, curtain filters, membrane filters and disc filters are used as filter type. Substances that cannot pass through the filter with a hole size of approximately 50 μm are released back into the sea water where the operation takes place. Filtering equipment is generally used in ballasting processes. Filters used in pre-treatment systems generally have a self-cleaning system against the clogging problem. Figure 1.4 shows the filter for the BWT system.

Figure 1.4 : A filter used in ballast water treatment system.

1.2.1.2 Hydrocyclone

Hydrocyclone separation method provides purification of the water by pushing the solid particles, which are in the sea water and whose density is higher than the sea water, towards the wall of the separator by centrifugal forces (Werschkun et al., 2012). The vacuum that occurs after the pressure drop in the center provides the formation of a second flow that turns to the opposite side in the center (Kurtela, 2010). Thus, while small particles move upwards, large particles are thrown from below. Organisms with a density less than the density of sea water come out of the clean water outlet of the separator. This situation creates inefficiency in the ballast water treatment method used in the second stage. Mechanical filters are more efficient than hydrocyclone separators (Waite et al., 2003).

1.2.2 Physical methods

Physical treatment methods are the methods used to inactivate organisms and do not require a chemical treatment, and are considered safer for human health than chemical methods. Physical treatment methods can be used in ballasting and deballasting operations.

1.2.2.1 Heat treatment

It is a method of reclaiming the sea water to be taken into ballast tanks by using the residual heat source on the ship (Thornton et al., 2003). It is based on the inactivation of the living organisms in it by heating the sea water to be taken into the tanks. High temperatures in the range 40–55 ◦C display good inactivation capability for microorganisms such as bacteria, phytoplankton, and zooplankton (Quilez-Badia et al., 2008). Especially in cold waters, high energy is required to raise the ballast water to these temperatures. In the ports, the ship's generators and boilers are operating actively, but sufficient energy can not be obtained from the waste heat of the generator and boiler to heat the ballast water. While the ship is on voyage, the waste heat production due to the operation of the main engine is much higher and ballast operation can be performed while cruising, but this process takes a very long time. In addition, heating the ballast water damages the tank lining and causes corrosion in the tank. Against these negative aspects, it is a very environmentally friendly method due to the absence of chemical by products in the heat treatment process and the use of waste heat (Sayinli et al., 2022).

1.2.2.2 Ultraviolet (UV) methods

UV radiation is one of the most common disinfection treatments for effectively damaging the DNA and other cellular structures that may lead to the inhibition of reproduction or to cell death (Santos et al., 2013; Giannakis et al., 2016). UV light penetrates the cell membranes of microorganisms and disrupts the DNA in the cells and the structure of the cell. Disruption in DNA and cell structure causes DNA modifications, inhibition of DNA replication and inactivation of organisms (Sayinli et al., 2022). In BWT systems with UV irradiation technology, organisms are inactivated with high efficiency but Some organisms have high resistance to UV rays due to their size and morphology (Matousek et al., 2006).

No chemicals are used or produced in this method. The efficiency of the system depends on the turbidity and conductivity of the water because the high turbidity of sea water in UV systems reduces the efficiency of the system (Makuei et al., 2022). UV separation method is generally used in ballast and deballasting operations. Due to the low transmittance of UV radiation in turbid waters, a high UV dose is needed and this causes large energy consumption in high turbidity waters (Lakshmi, Priya, & Achari, 2021). The high energy consumption of UV systems can be the biggest disadvantage of these systems. UV systems generally consist of a filter and a UV reactor. Figure 1.5 shows the BWT system of a tanker ship.

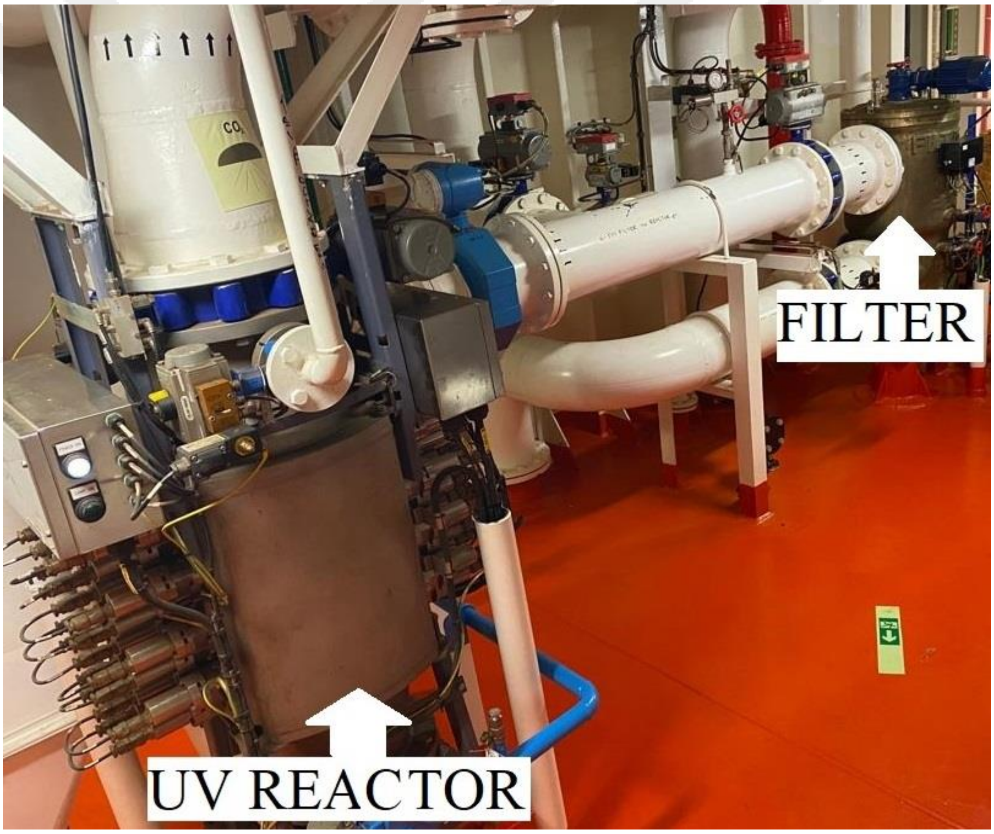

Figure 1.5 : BWT system of a tanker ship.

1.2.2.3 Ultrasound methods

Ultrasonic purification method is a physical purification method and is based on the generation of high frequency vibration, which causes the formation of cavitation bubbles in the liquid. Upon bursting of these cavitation bubbles, the cell membrane is ruptured and microorganisms are destroyed (Viitasalo et al., 2005). No chemicals are used or produced during treatment.

1.2.3 Chemical methods

Another treatment option used for ballast water treatment is chemical methods. These methods inactivate the microorganisms in sea water by adding or creating chemicals. Generally, systems with these methods have filtration equipment in the first stage. Chemical methods consist of biocides and electrochemical methods.

1.2.3.1 Biocides

Biocide is a chemical substance used to inactivate microorganisms in water. Depending on the mode and time of action of these chemicals, they can be used during the ballast-deballast operation or during the course of the ship. Biocides are divided into two groups as oxidizing biocides and non-oxidizing biocides (Huber, Carré, & Zeno, 2010). Both types work similarly to pesticides and interfere with normal cell functions (Carney, 2011). Examples of oxidizing biocides are chlorine, chlorine dioxide, ozone, and hydrogen peroxide and examples of non-oxidizing biocides are acrolein, SeaKleen, and glutaraldehyde (Lakshmi et al., 2021).

Oxidizing biocides are known to inactivate microorganisms faster and cost less than non-oxidizing biocides. Biocides are stored in condensed solid or liquid form. The handling of this type of hazardous chemical by the ship crew is a risk for the ship crew. In order to minimize this risk, it is necessary to provide training to the ship's personnel for systems using such substances. The biocides to be used should be effective against most of the microorganisms found in sea water (Sayinli et al., 2022). In addition, it is important that it is of a type that can easily decompose in nature and will not harm living things other than those in the water.

1.2.3.2 Electrochemical (El-Chem) method

The electrochemical method is the most widely used chemical treatment method in ballast water treatment systems. Electrolysis is an electrochemical process in which direct current flowing through the electrolyte (ballast water) is used to form various compounds with significant oxidation capabilities and thus disinfection potential (Vorkapić et al., 2018). The use of electrochemical methods is divided into two methods as full stream (or direct flow) and side stream. In the full stream method, all of the sea water is passed through the electrolytic cell, and the resulting electric field can directly damage the cell membranes of the organisms and in some cases cause the death of microorganisms by oxidizing the substances in the cell structures without affecting the cell membranes (Drees et al., 2003). In the side flow method, sea water is taken from the main ballast water circuit with the help of a small circuit and this sea water is passed through the electrochemical cell to produce a concentrated disinfectant flow and a high concentration disinfectant is produced. The created disinfectant is then injected into the main ballast water circuit (Jee & Lee, 2017). Often systems with these methods include first-stage filtration equipment. The efficiency of electrochemical systems is affected by the salinity and temperature of seawater, the pollutants it contains and their concentrations. Figures 1.6 and 1.7 show drawings of full stream and side stream BWT systems.

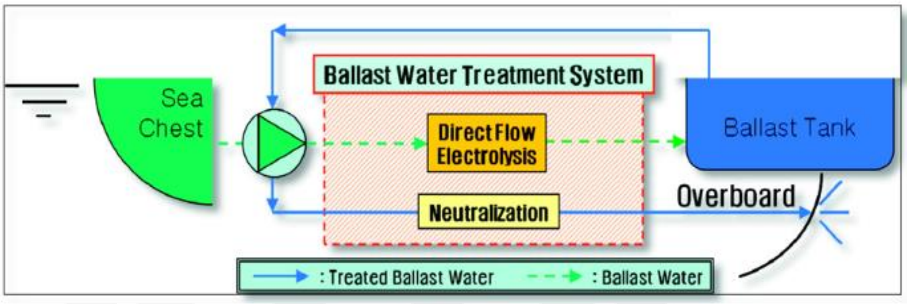

Figure 1.6 : Full stream BWTS method (Jee & Lee, 2017).

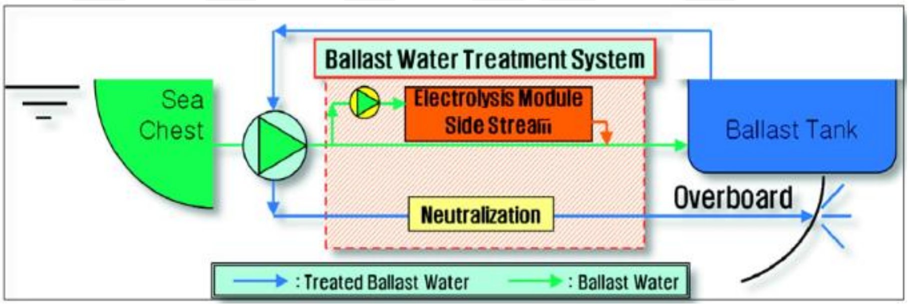

Figure 1.7 : Side stream BWTS method (Jee & Lee, 2017).

1.2.4 Mixed methods

Three main methods are used in ballast water treatment. Each of these methods has certain advantages and disadvantages when considering factors such as ship type and operation area. Considering the diversity of living organism in the ballast water, none of these three methods alone could produce the desired results in the USCG and IMO D2 standards. As a result of this situation, mixed systems have started to be used in order to provide the desired standards in ballast water treatment on ships. In the first stage, the purification of living microorganisms or solids in sea water was achieved by using mostly mechanical methods. In the second stage, physical or chemical methods are used. Generally, UV + filtering or electrochemical + filtering is used on ships.

1.3 Criteria for Selecting BWTS

There are many important criteria to consider when choosing BWT system for ships. Many criteria should be evaluated not only by looking at the efficiency of the equipment to be used, but also by the investment cost, operating cost, suitability for the ship and the area it covers.

The type of the ship and the capacity of the ballast tanks are one of the most important criteria in the selection of a ballast water treatment system. It is necessary to select an equipment suitable for the ship type and ballast capacity. In addition, there are many different criteria to be considered in BWT system selection (American Bureau of Shipping, 2014; IRClass, 2018; Tamplain, 2019). These criteria are explained in detail below.

Type approval and the region where the ship will operate: The BWT system to be selected must be approved by flag management, port management or G8 and G9 from the guides published by IMO. When choosing BWT system, it should be paid attention to the type approval of the product to be selected. The type approval of the equipment must be valid in the territorial waters of the country where the ballast operation will take place. Some BWT system meet IMO standards, while some only meet USCG standards. BWT system that meets both standards is also available. Therefore, it should be known what standards the BWT system will have to be selected according to the region where the ship will operate. For example; only the BWT system of a ship operating in the Mediterranean and Black Sea must comply with IMO standards. The BWT system of a ship operating between Turkey and the USA must meet IMO standards in Turkish territorial waters and USCG standards in US territorial waters. Ship equipment to operate in this region must have both IMO and USCG standards. Therefore, equipment should be selected considering the region where the ship will operate in BWT system selection (Berntzen, 2013).

Ship type and ballast water capacity: While determining the treatment capacity of the equipment in the selection of BWTS, the flow capacity of the ballast pump and the capacity of the ballast water tanks should be considered. Ballast water capacity of ships varies according to the types of ships. Ballast capacity of passenger and container ships is less than tanker and dry cargo ships. Flow capacities of ballast water pumps can be different from each other in different ship types with the same dimensions. Therefore, the BWT system must meet the ballast water capacity of the ship (Tamplain, 2019).

Characteristic of ballast water: The temperature, turbidity and salinity of sea water affect the efficiency of BWT system. The high turbidity of sea water in UV systems reduces the efficiency of the system (Makuei, Ketabchi, & Peleato, 2022). In the electrolysis method, if the salinity of the sea water is below a certain level, the efficiency of the system decreases (Yang, Wang, Han, & Pan, 2019). For a ship that will carry out commercial activities in regions where the sea water is cold, the heat treatment method should not be chosen because the efficiency of the system decreases in cold waters. Therefore, in the selection of BWT system, equipment should be selected in accordance with the characteristic feature of sea water, taking into account the commercial activity area of the ship.

System dimensions: It is easier to equip the BWT system on newly built ships than on an existing ship. For newly built ships, BWTS is designed considering the whole of the ship, but finding a place to equip the system for an existing ship is challenging. Not only the dimensions of the BWT system, but also changes in the piping system must be considered because on ships this additional piping can be a problem. BWT system taken on an existing ship can be more advantageous for the area, consisting of many modules instead of a single module. Therefore, the area covered by the equipment is important for the ship to be selected for the BWTS (Tamplain, 2019).

Manufacturer reliability: Today, many companies produce BWT system. When choosing BWT system, it should be taken into account whether the manufacturer company has a worldwide service network. In the event of a possible malfunction in the BWT system of a ship operating in international waters, the commercial activity of the ship may be damaged if spare parts or technical service are not provided to the ship. In addition, the supply of chemicals is also very important in BWT system that needs chemicals in the treatment process. Therefore, it is important that the manufacturer of the ballast water treatment system to be selected has a worldwide spare parts supply and technical service. Repairing a possible malfunction in the system in a minimum time prevents the commercial activity of the ship from being damaged. This situation is very important for both ship personnel and ship operator. In addition to all these; reference information should be obtained on how many more ships the manufacturer has integrated this system into.

Investment and operating cost: In addition to the efficiency of the BWT system to be selected, the investment, installation, maintenance and operating costs are very important for the shipowner. The investment and installation cost can be calculated at the initial purchase of the system, but it is more difficult to estimate as maintenance and operating costs differ from ship to ship. Estimated operating and maintenance costs should be calculated in system selection and the sum of all costs should be considered in product selection (Tamplain, 2019).

Energy consumption: Since the amount of energy consumed by the BWT system to be selected will directly affect the operating cost, it is important that it be at a minimum level. The excess energy consumption of the BWT system to be integrated into the new construction ships may cause an extra load to the ship generators, so the generator planned to be installed may have a higher capacity. Therefore, it is very important that the energy consumption of the system to be selected is minimal (IRClass, 2018).

Crew safety and health: Some ballast water treatment systems require chemicals for treatment. In the case of selecting BWT system that needs such chemicals, it is very important for the health and safety of the ship crew to provide the necessary training. In addition, the correct storage and ventilation of the chemicals to be used should be considered.

Delivery and installation time of the system: Shipowners always want their ship to be actively engaged in commercial activities. Therefore, the integration of the ballast water treatment system to be selected on an existing ship in a minimum time period and the active commissioning of the system plays an important role in the selection of the BWTS.

2. MULTI CRITERIA DECISION ANALYSIS METHODS

Multi criteria decision analyses (MCDA) are methods that enable the selection of the best alternative among multiple and simultaneously applied criteria. These methods are applied in solving problems involving quantitative or qualitative criteria. MCDA is a multi-step process consisting of a set of methods to objectively and transparently structure decision-making processes in the problems encountered (Langemeyer et al., 2016).

The decision analysis process is a systematic way for an individual or group to make informed decisions in the face of complex problems (Clemen & Reilly, 2001). Person experience the decision-making process at every stage of their life. In routine decisions, the person often adopts intuitive approaches; in the decisions concerning a company or a group, it becomes a necessity to replace intuitive approaches with scientifically-based approaches. A scientific decision-making process is based on modeling and analysis according to criteria. This process also necessitates acting logically for rationality and efficiency (Uludag and Dogan, 2016). The purpose of the decision maker person or group is different for each type of problem. In selection problems, the aim is to choose the best among the alternatives, in ranking problems, the aim is to rank the alternatives from the best to the worst, and in classification problems, the aim is to classify the alternatives according to certain criteria.

Many classical or fuzzy logic based methods are used for the solution of MCDA problems (Uludag and Dogan, 2016). To reach the best solution with MCDA, different multi-criteria decision making methods can be used. After determining the problem, the decision maker person or group should evaluate the nature of the problem and the characteristics of the process in order to reach a solution. For the solution, it is necessary to decide which MCDA method is the appropriate method. Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), MAUT, UTA, MACBETH, ELECTRE I, TOPSIS are recommended methods to choose between objective programming and data envelopment analysis options (Ishizaka&Nemery, 2013).

The Analytical Network Process (ANP) is a generalization of the Analytical Hierarchy Process (AHP) that takes into account the dependency between its elements (T. L. Saaty, 2006). Many decision problems can not be structured in a hierarchical structure because they involve the interaction and dependency of higher elements in the hierarchical order with lower elements. Therefore, the Analytical Network Process is represented by a network rather than a hierarchical structure (T. L. Saaty, 2006).

Multi Attribute Utility Theory (MAUT) is a structured methodology designed to address obligations between different targets (Parihar & Bhargava, 2019). MAUT is a method that supports the decision-making group or individual to choose from a limited number of alternatives. Thanks to this method, the decision maker or group evaluates each of the limited number of alternatives separately and reaches the result (Jansen, 2011).

UTilité Additive (UTA) is an MCDA method designed to prioritize alternatives under multiple criteria by identifying the importance of criteria. This method is a powerful approach that is widely used to obtain the priority vector of criteria and alternatives (Rezaeinia, 2022).

Measuring Attractiveness with the Categorical-Based Evaluation Technique (MACBETH) is a method that enables the attractiveness of alternatives to be measured based on qualitative judgments about the attractiveness differences of the alternatives in the decision-making process of the decision maker or group (Banae Costa & Chagas, 2004). In this method, iterative inquiry technique including pairwise comparisons is used and a qualitative choice is requested from the decision maker. The answers obtained as a result of the pairwise comparison are entered into the MACBETH decision support system and their consistency is verified (Marcelino et al., 2019).

ELECTRE is an MCDA method based on partial addition. The idea of this method is to rank the alternatives based on the fit and discord index calculated from the data extracted from a decision table (Sabaei et al., 2015). This method consists of 4 main parts. In the first part, each criterion should be weighted and a threshold function should be established. In the second part, fit and discord index should be calculated for the alternative pair. In the third part, the superiority degree should be calculated for the alternative pair according to the fit and incompatibility index. In the last part, partial ranking is made for all pairs of alternatives.

TOPSIS (Order of Preference Technique by Similarity to Ideal Solution) is widely used among MCDA methods. The ideal solution is defined on the basis of the best accepted values from all available set of values for each criterion (Hwang and Yoon, 1981). The negative ideal solution is defined as one that should not be chosen among the alternatives. The solution is reached by ordering the selected alternatives according to their ideal and negative ideal distances (Kobryń & Prystrom, 2016).

Analytical Hierarchy Process (AHP) is one of the most preferred methods among the aforementioned methods, as it provides significant convenience to the users in terms of mathematical operations and intelligibility (Saaty, 1987). AHP can be used alone in MCDA problems as well as in combination with different methods. Advantages of the AHP method; it enables to choose the best alternative among the alternatives, reduces complex problems to a simple and very flexible model, provides an easily applicable decision-making methodology that helps the decision maker or group to make decisions with certainty (Lapevski & Timovski, 2014). In addition, the AHP method plays an important role in quantitative and qualitative or objective or subjective evaluations, has a wide use, the general view of the problem is easily represented and can be applied quickly and precisionly with computer software (Oguztimur, 2019). In this thesis study, the AHP method was preferred among the MCDA methods due to the advantages mentioned above.

2.1 Analytical Hierarchy Process (AHP)

AHP is a technique used in modeling and solving multi-criteria decision problems (Rajput et al., 2018). The types of problems to which the AHP technique is applied are generally selection problems, evaluation problems, resource allocation problems, and benchmarking problems. AHP transforms complex problems into a hierarchical structure and is based on pairwise comparisons (Brunelli, 2015). The values obtained as a result of the comparison are called the pairwise comparison matrix. After these matrices are analyzed, it reveals which of the two criteria being compared is more important and preferable. AHP evaluates the problem in a multi-layered hierarchical structure. The decision maker or group decomposes the problem into layers in a hierarchical structure. Thus, the problem is reduced to different sub-problems. The solution of the decision problem is reached by solving the reduced sub-problems.

2.1.1 Hierarchical structure

The hierarchical structure is the set of layers formed by reducing the problem to more than one sub-problem in order to present the problem in detail. In the analytic hierarchy process, the decision problem is transformed into a hierarchical model. This hierarchical model consists of goals, criteria, and alternatives (Brunelli, 2015). In the hierarchical structure, the lower-level element should be associated with the next-level element or elements (Ishizaka & Labib, 2011).

At the top of the hierarchical structure is the goal. While determining the goal, it should be known which problem will contribute to the solution. After the goal is determined, the second step is the criteria. With the determination of the goal, criteria and alternatives begin to emerge. Criteria are the intermediate elements used to achieve the goal. The criteria form the middle part of the hierarchical structure. Alternatives form the lower part of the hierarchical structure. An example of hierarchical structure consisting of three levels is shown in Figure 2.1.

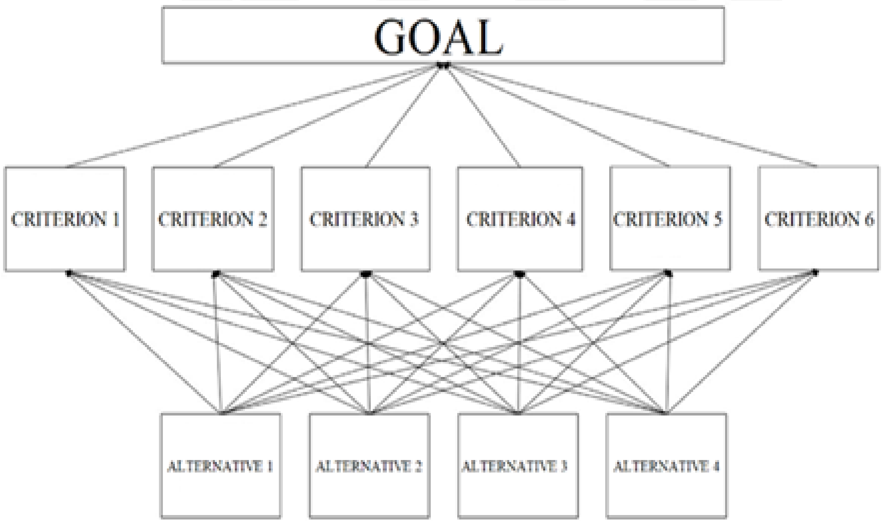

Figure 2.1 : Three level hierarchical structure in the AHP.

2.1.2 The fundamental scale

In the analytic hierarchy process, criteria, sub-criteria, and alternatives are compared in pairs. In these comparisons, judgments are quantified using a fundamental scale of 1-9. If the decision maker or group has knowledge of the actual values obtained from a numerical scale, these values can also be used in pairwise comparisons. Table 2.1 shows fundamental scale values.

Table 2.1 : The fundamental scale (Saaty, 1987).

Preference level	Intensity of importance on an absolute scale
Equally important	1
Moderately more level important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Represent intermediate values	2, 4, 6, 8

2.1.3 Pairwise comparison matrices and determination of superiorities

In AHP, the fundamental scale is used for pairwise comparisons between elements. The criteria are digitized using the fundamental scale (Saaty, 1987). Pairwise comparisons between criteria are made according to their common features. The person or group making the comparison accepts the unimportant one among the criteria as a unit and expresses how many times the other criterion is more important and preferable than this unimportant criterion by choosing the appropriate numerical value from the fundamental scale table. Pairwise comparison matrices are made separately for criteria and alternatives. The most important criterion in the same cluster can be nine times higher than the least important criterion considered as a unit (Brunelli, 2015).

The numerical values of the judgments reached in the pairwise comparisons, which are converted with the help of the fundamental scale, are entered into a matrix and the pairwise comparisons matrix is obtained. In a problem where n number of criteria are determined in the decision-making process, a comparison matrix is created by making n(n–1)/2 comparisons. In the comparison matrix, if the importance level of the ith criterion and the jth criterion is indicated by aij, the comparison matrix will be written as the A matrix shown below.

$$A = \begin{bmatrix} a_{11} & a_{12} & . & a_{1n} \\ a_{21} & a_{22} & . & a_{2n} \\ . & . & . & . \\ a_{n1} & a_{n2} & . & a_{nn} \end{bmatrix} \tag{2.1}$$

After the comparison matrix is created, the B normalization matrix is created by dividing each column value by the corresponding column sum, using the following formulation.

$$b_{iJ} = \frac{a_{iJ}}{\sum_{i=1}^{n} a_{iJ}} \tag{2.2}$$

$$B = \begin{bmatrix} b_{11} & b_{12} & . & b_{1n} \\ b_{21} & b_{22} & . & b_{2n} \\ . & . & . & . \\ b_{n1} & b_{n2} & . & b_{nn} \end{bmatrix} \tag{2.3}$$

In order to determine the importance levels of the criteria by using the B matrix, the arithmetic average of the row components of the B matrix is taken and the W column vector is obtained.

$$W = \begin{bmatrix} w_1 \\ w_2 \\ . \\ w_n \end{bmatrix} \tag{2.4}$$

The authenticity of the AHP results depends on the consistency of the pairwise comparison matrices made by the individual or group in the decision-making process (Soydan, 2021). Therefore, AHP proposes a consistency analysis that will enable this consistency to be measured. If the consistency ratio is less than 0.10 as a result of the consistency analysis, the pairwise comparison matrices are considered to be consistent. If the consistency ratio is greater than 0.10 as a result of the consistency analysis, the pairwise comparison matrices should be reconstructed (Saaty, 1987).

The formulas required to calculate the consistency analysis are shown below.

For the calculation of λ, the matrix product of the comparison matrix A and the priority vector W is calculated, and as a result of this calculation, the column vector D is obtained:

$$D = \begin{bmatrix} a_{11} & a_{12} & . & a_{1n} \\ a_{21} & a_{22} & . & a_{2n} \\ . & . & . & . \\ a_{n1} & a_{n2} & . & a_{nn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ w_n \end{bmatrix} \tag{2.5}$$

It is necessary to divide the reciprocal elements of the D matrix and the W column vector to obtain the base value (E) for each evaluation factor. The arithmetic mean of these values gives the basic value λ for the comparison (Emin Cihangir, 2021):

$$E_i = \frac{d_i}{w_i} \quad (\mathrm{i} = 1,2, \dots, \mathrm{n}\ ) \tag{2.6}$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \tag{2.7}$$

After calculating λ, the Indicator of Consistency (CI) can be calculated using the formula below.

$$CI = \frac{\lambda - n}{n - 1} \tag{2.8}$$

In the last step, the Consistency Ratio (CR) is obtained.

$$\text{Consistency Ratio (CR)} = \frac{\text{Indicator of Consistency (CI)}}{\text{Random Index (RI)}} \tag{2.9}$$

The Random Index (RI) is the standard correction value and varies with the size of the comparison matrix. Table 2.2 shows random index values.

Table 2.2 : Random index (Saaty, 1987).

N	1	2	3	4	5	6	7	8	9	10
R1	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.1.4 Synthesis

Synthesis is the last part of the solution steps in the analytic hierarchy process. Synthesis process for each alternatives; It is the sum of the products obtained by multiplying the relative importance value of the relevant alternatives from a criterion and the relative importance value of the relevant criterion for all criteria. The total values obtained allow the decision maker or group to sort among the alternatives according to these values.

The formula for calculating the holistic significance values for the alternatives;

$$S_J = \sum_{i=1}^{n} w_i p_{iJ} \tag{2.10}$$

s_j: j^{th} option (j = 1, 2, …, m)

w_i: weight of the i^{th} criterion (i = 1, 2, …, n),

p_{ij}: shows the weight of the j^{th} option according to the i^{th} criterion (i = 1, 2, …, n; j = 1, 2, …, m).

3. EVALUATION OF BWTS EQUIPMENT INTEGRATED BY THE MARITIME COMPANY TO ITS SHIPS BY AHP METHOD

The ballast water convention entered into force on 8 September 2017 and since then all new-built ships must be equipped with ballast water treatment systems. Implementing ballast water treatment systems into existing ships must be completed before September 8, 2024. So far, thousands of ships have been equipped with ballast water systems. Due to the lack of on-board experience, the selection of the system was carried out according to the following predetermined criteria based on ship characteristics, economic feasibility and reliability of the manufacturer, etc.

- Type approval and the region where the ship will operate
- Ship type and ballast water capacity
- Characteristic of ballast water
- System dimensions
- Manufacturer reliability
- Investment and operating cost
- Energy consumption
- Crew safety and health
- Delivery and installation time of the system

Nowadays there are many different brands and types of BWTS equipment that meet the mentioned criteria. However, in the light of the experience gained with the use of the systems, it has now become possible to evaluate the systems in terms of their use on the ship.

Within the scope of the study, UV and electrochemical (El-Chem) systems, the two most common types of BWT system, were evaluated based on the experience of expert seafarers. While determining the evaluation criteria, the failure reports of the BWT systems of the selected maritime company were examined and bilateral interview with expert seafarers were taken into account. Then, a survey was developed based on these reports and bilateral interviews. The data obtained through this survey were used to evaluate the systems in the AHP process.

3.1 The Background of the Study and Data Gathering for BWTS Type Evaluation

In this study, BWT systems installed on 6 tankers in the fleet of a maritime company were evaluated. The maritime company integrated El-Chem 1 brand BWT systems to its twin ships built in 2015. In 2019, it integrated UV-1 brand BWT systems to its tanker ships of the same tonnage. In 2021, UV-2 brand BWT systems were integrated to two tanker ships of different tonnages built before 2013. Table 3.1 shows the characteristics of the ships and BWT systems owned by the maritime company.

Table 3.1 : Characteristics of the maritime company ships.

BWTS type and brand	Ship type and DWT	New built/retrofit installation	On board experience with the particular system since
El-Chem 1	Tanker – 20K	New built	2015
El-Chem 1	Tanker – 20K	New built	2015
UV-1	Tanker – 20K	New built	2019
UV-1	Tanker – 20K	New built	2019
UV-2	Tanker – 6K	Retrofit	2021
UV-2	Tanker – 50K	Retrofit	2021

The data was collected in a two-phase process to evaluate the systems. In the first phase, the failure reports of the BWT systems of the ships during their use were examined and bilateral interviews were conducted with expert seafarers. Through these bilateral interviews, the perspectives of each expert seafarer on the widely used El-Chem and UV systems were consulted (interviewed personnel of the ships are the masters, the chief officers, chief engineers, second engineers, and the electrical officers)

In the second stage of data gathering process, a survey was prepared in the light of the evaluations made in the first stag. This survey was presented to the 64 expert seafarers and 50 of the sefarers have answered.

All expert seafarers who participated in the survey were firstly asked which type of BWT system they would prefer to work in between El-Chem and UV systems. Table 3.2 shows which type of BWT system the expert seafarers would like to work in.

Table 3.2 : BWTS type preferences of surveyed expert seafarers.

BWTS Type	Deck Officer Score	Engine Officer Score	Total Score
UV	11	20	31
El-Chem	3	2	5
UV and El-Chem	10	4	14

All seafarers who participated in the survey were firstly asked which type of BWT system would you prefer to work in between El-Chem and UV systems. 62% of the seafarers preferred UV type BWT system, 10% preferred El-Chem type BWT system and 28% preferred both types of BWT systems. When we analyze the survey results for two different departments (engine-deck) working on board, it is seen that 77% of the engine department crew (chief engineer, second engineer and electrical officer) prefer UV type BWT system, 8% prefer El-Chem type BWT system and 15% prefer both types of BWT system. On the other hand, 46% of the deck department crew (master and chief officer) preferred UV type BWT system, 12% preferred El-Chem type BWT system and 42% preferred both types of BWT system.

3.1.1 Setting features for system evaluation

In the first phase of the data gathering process, after analyzing the failure reports written by the ship personnel of the maritime company and collecting the opinions of the expert seafarers working on the systems, the most prominent problems regarding the use of systems using electrochemical systems and UV systems were identified.

The maritime company has been using electrochemical systems on two of their ships since 2015. The problems related to the use of electrolysis type BWT systems are summarized as follows:

- Ship crew are required to handle chemicals.
- It consists of a lot of different equipment.
- Because the system is complicated and contains certain hazards, the ship's crew need more training.
- It takes up a lot of space and the equipment is usually located in various parts of the ship. In case of malfunction and routine checks during operation, this is tiring for seafarers.

- The general maintenance of the systems is complex and difficult.
- The TRO (Total Residual Oxidant) sensor, which measures the content of ballast water in ballasting or deballasting operations, needs chemical solutions for measurement. Due to the expiration date of the solutions used, a lot of stocks cannot be made. The solutions must be followed regularly and supplied regularly by the maritime company.
- The fact that the pipes of the TRO sensor unit are thin and the pipes caused by the solutions used in it become clogged. In addition, in cases where the unit pipes are punctured due to the corrosive nature of sea water, sea water damages the electronic parts in the unit.
- In the electrolysis unit where the electrolysis event takes place, sea water forms corrod over time. Manufacturers have chemical washing systems to remove rust formed in the unit. These systems are not very efficient for cleaning the electrolysis unit. Therefore, the electrolysis unit is removed and cleaned outside in chemical liquid for at least 1 day. This process is tiring for seafarers and exposes them to chemicals.
- The electrolysis unit needs to be cooled. It causes different equipments to stop due to temperature in ships with a problematic general cooling system.
- The solenoid valves of the neutralization unit used in the deballlast operation are clogged due to the chemical used. Cleaning the solenoid valves before the operation reduces the possibility of clogging, but it causes extra time and labor loss, especially for the personnel on ships with frequent loading operations.
- The mesh range of the filtering elements used on the system is quite low. So it gets clogged frequently. In many of these systems, filters with the self-cleaning feature are used, but the ballast water treatment capacity decreases during cleaning and the system cannot clean itself completely. Therefore, cargo loading-unloading operations are affected. The filters of these systems, which are used especially in large tonnage ships, are removed and cleaned by the seafarers. This process is tiring for seafarers and may expose them to chemicals.
- Since it consists of many equipment, electrical faults occur frequently.
- In general, the system's past alarm list is longer as more problems arise in such systems. This situation creates a wrong impression about the ship for the inspectors who come to the ship at various periods.

The maritime company has been using UV-1 BWT systems on two tanker ships since 2019 and UV-2 BWT systems on two tanker ships since 2021. After the failure reports written by the ship's crew for the UV type BWT systems of the maritime company are examined, and when the opinions of expert seafarers working on UV type BWT system of two brands are taken, the problems related to the use of UV type BWT systems are summarized as follows:

- For some brands of BWTS equipment, UV lamp replacement is done frequently.
- As a result of the deformation of the outer shell of the UV lamps, the direct contact of sea water to the lamp causes the driver unit of the lamp to burn.
- Compressed air usage is high for some brands of BWTS equipment. Therefore, it causes the ship's service air compressor or main air compressor to work more.
- Air-electric controlled actuators on the system circuits may jam or fail to operate.
- In some brands, the self-cleaning feature of the filtering elements is not very efficient. Ballast water treatment capacity is decreasing. Therefore, cargo loading-unloading operations are affected. The filters of the systems are removed before or after the operation and cleaned by the seafarers. This process may expose seafarers to chemicals.

As a result of the evaluation of the problem areas of both electrochemical and UV BWT systems, the following characteristics were determined for an ideal BWT system to be used on board;

- Feature 1: Does not contain chemical handling,
- Feature 2: To be easy of operational use,
- Feature 3: To be easy to maintenance,
- Feature 4: Rarely alarms and malfunctions,
- Feature 5: Small footprint and simplicity of system equipment,
- Feature 6: Easy routine controls during operation,
- Feature 7: Does not require preparation before ballast operation,
- Feature 8: Little training needed prior to use.

As the features of an ideal BWT System was defined in the first phase, a survey were prepared for the second phase of data gathering. Exact the same survey was presented to two different groups of experts (i.e., deck officers and one to the engine officers) with additional questions regarding their occupational position on ship. The purpose of grouping the expert seafarers in to two groups was to reveal the similar and different opinions of the employees of two different departments. 50 expert people working on board answered the survey digitally. Figure 3.1 shows the rank and number of experts who answered the survey.

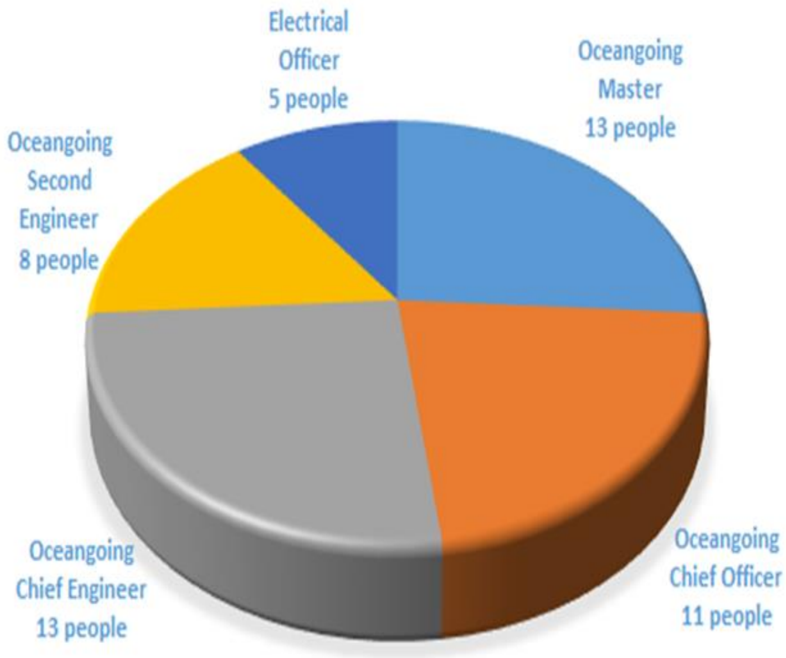

Figure 3.1 : Number and ranks of experts participating in the survey.

3.1.1.1 Determining criteria for AHP

One of the questions posed to the experts in the questionnaire was to rank the features identified for an ideal BWT system in the first stage of the data gathering process from most important to least important.(i.e., 1: The least important; 8: The most important.) According to the outcomes of the survey, six different criteria were determined for evaluation of the BWT systems from expert seafarers' perspective:

- **Criterion 1- Operational ease of use and less training requirement prior to use:** Ships are complex structures consisting of many different systems working together. New personnel joining these complex structures may encounter different brands and types of equipment performing the same task for the first time. The use of newly encountered equipment is sometimes easy and sometimes difficult. For the use of some equipment, personnel may need to be trained in advance. The fact that the operational use of the BWT system to be selected is easy for the ship's officers and requires very little training before use is a great advantage for the personnel on board.

- **Criterion 2- No chemical handling requirment:** During the deballast operation in electrochemical BWT systems, a neutralizing agent (Sodium Bisulfite, etc.) is dosed to inactivate the residual oxidants in the ballast water. In order to store and use this neutralizing chemical on the ship, first of all, the necessary training should be given to the ship's personnel. It is important to take the necessary safety precautions for these chemicals and to ventilate the area where they will be stored. Since it is inevitable for the crew of the ship to be in close contact during the transportation and use of chemical substances, the crew has negative opinions about systems that use this type of chemical. In some brand UV systems, chemical liquid is used to clean the UV reactor. This chemical liquid must be kept in the designated chemical store areas on the ships. During the filling of this chemical liquid into the reactor cleaning unit, the crew of the ship has to take special protective measures.
- **Criterion 3- Rare alarms and malfunctions:** Generally, ballast and deballast operations take place during cargo loading or unloading. The ship's officer responsible for the loading or unloading operations of the cargoes wants everything to go smoothly in these operations that may take days. Frequent malfunctions or sounding of the alarm in some BWT systems affect the ship's operations and also distract the ship's officer. For example; A chief officer working on a tanker ship may also need to fill the cargo tanks to 98% capacity. During the critical loading capacity, he has to give his full attention to the level of the cargo tanks. But it may also have to do the deballast discharge. An alarm that may sound in the BWT system may distract the chief officer and cause him to misoperate.
- **Criterion 4- No preparation requirement prior to ballast operation**: Before ballast and deballast operations, in case of jamming of air or electrically controlled valves of some BWT systems, on-off is performed. In particular, the solenoid valves in the dosing circuits of the neutralizing chemical of the El-Chem system are jammed. These solenoid valves may need to be cleaned before the deballlast operation. In addition, the dosing pipe of the tank chamber containing the neutralizing chemical should be cleaned against the possibility

of clogging. The first-stage mechanical filter in El-Chem systems or UV systems must be cleaned by the ship's personnel at regular intervals.

- **Criterion 5- Easy maintenance:** Since BWT systems are generally used in cargo loading or unloading operations, in case of a failure, the failure must be resolved within a limited time so that the cargo operation is not affected. This creates stress for the ship's engine officers responsible for maintenance. The ease of maintenance of the BWT system before or in the event of a breakdown is a great advantage, especially for engine officers.
- **Criterion 6- Small footprint of the system and easy routine controls:** Some BWT systems are located in various floors and compartments due to space shortages, especially in retrofit ships. In the event of a malfunction in these equipments or during routine controls, there is a serious loss of time due to being in many different locations. The large size of the equipment also makes it difficult to maintain.

3.1.2 Application of AHP method for BWTS type evaluation

After the criteria for two alternatives were determined, a hierarchical structure was created for the application of the AHP technique for BWTS method evaluation. Figure 3.2 shows the hierarchical structure of the AHP method to be applied.

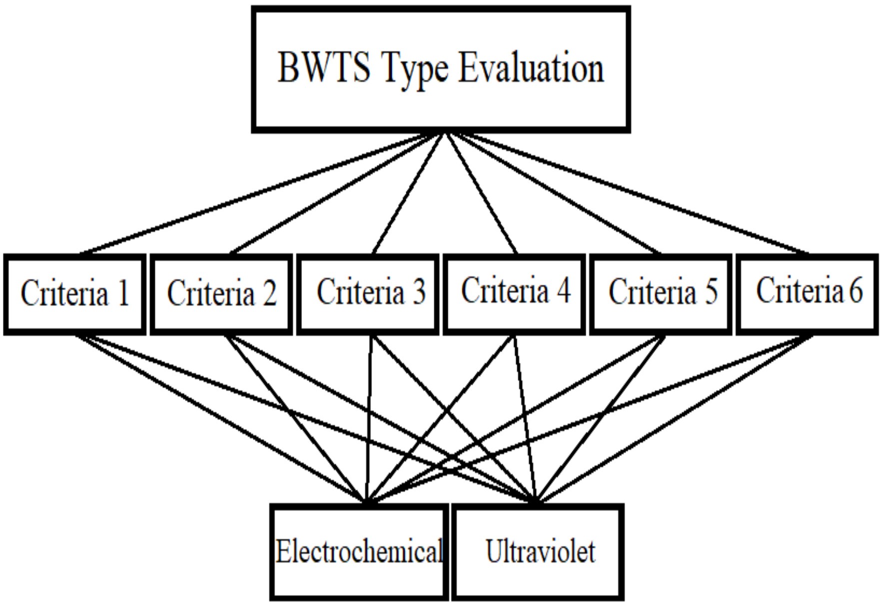

Figure 3.2 : Hierarchical structure of BWTS type evaluation.

Before creating the pairwise comparison matrices, the characteristics that an ideal BWT system should have were ranked based on the survey results. For this purpose, the total scores and per capita average scores of these features were calculated. Table

3.3 shows the total scores given for eight features according to the survey results. Table 3.4 shows the scores per person capita for eight characteristics according to the survey results.

Table 3.3 : The total scores of eight features according to the survey results.

Features	Deck Officer Score	Engine Officer Score	Total Score
Does not contain chemical handling	117	138	255
To be easy of operational use	156	158	314
To be easy to maintenance	137	172	309
Rarely alarms and malfunctions	152	168	320
Small footprint and simplicity of system equipment	61	98	159
Easy routine controls during operation	93	75	168
Does not require preparation before ballast operation	72	64	136
Little training needed prior to use	76	63	139

Table 3.4 : The total scores of the eight features per person.

Features	Deck Officer Score	Engine Officer Score	Total Score
Does not contain chemical handling	4.88	5.31	5.10
To be easy of operational use	6.50	6.08	6.29
To be easy to maintenance	5.71	6.62	6.17
Rarely alarms and malfunctions	6.33	6.46	6.40
Small footprint and simplicity of system equipment	2.54	3.77	3.16
Easy routine controls during operation	3.88	2.88	3.38
Does not require preparation before ballast operation	3.00	2.46	2.73
Little training needed prior to use	3.16	2.42	2.79

According to the deck officers, the most important feature of the BWT system is the easy of operational use, while the most important feature according to the engine officers is the ease of maintenance. The most important feature that both departments have jointly determined is that the system gives fewer alarms and malfunctions. According to the deck officers, the system's small footprint and simplicity was the least important feature, while the least important feature among the engine officers was that it required little training before use. The most insignificant feature common to both groups was that it required preparation before ballast operation.

According to the results of the survey, pairwise comparison matrices were created for the six criteria determined before the application of the AHP method. While creating the pairwise comparison matrices, the sum of the scores in the survey results was used.

After determining the eight features that a BWT system should have, the features that are close to each other were combined in order to obtain more realistic results of the AHP technique application. Since the ease of use of the equipment brings with it little training for the expert seafarers before use, these two features that are close to each other were combined. The small footprint of the BWT system also makes it easy for routine checks. These two features are also combined with each other. In addition, it is clearly seen that the features that expert seafarers want a BWT system to have support each other. Table 3.5 shows the total scores obtained from the criteria according to the survey results.

Table 3.5: The total score received by the criteria.

Criterions	Total Score
C1: Operational ease of use and less training requirement prior to use	227
C2: No chemical handling requirment	255
C3: Rare alarms and malfunctions:	320
C4: No preparation requirement prior to ballast operation	136
C5: Easy maintenance	309
C6: Small footprint of the system and easy routine controls	163

3.1.3 Evaluation of BWTS type with application of AHP

For the application of the AHP technique, firstly, a pairwise comparison matrix table is created for the level of importance of the criteria. In order to create the pairwise comparison matrix table, the ratios of the total scores of the criteria calculated according to the survey results to each other were used. Table 3.6 shows the ratios of the total criteria scores used to create the pairwise comparison table.

Table 3.6 : The ratios of the total scores of the criteria to each other.

Criteria	Total Score	C3	C5	C2	C1	C6	C4
Criterion 3	320	1					
Criterion 5	309	1.036	1				
Criterion 2	255	1.255	1.212	1			
Criterion 1	227	1.410	1.361	1.123	1		
Criterion 6	163	1.963	1.896	1.564	1.393	1	
Criterion 4	136	2.353	2.272	1.875	1.669	1.199	1

After calculating the ratios of the total scores obtained by the criteria according to the survey results, the importance values were determined. The purpose of determining the criteria ratios is to determine the importance levels in the pairwise comparison matrix. Table 3.7 shows the importance values according to the criteria ranges determined.

Table 3.7 : Importance values according to the specified criterion intervals.

Criterion ratio	Importance values
1.00-1.15	2
1.15-1.30	3
1.30-1.45	4
1.45-1.60	5
1.60-1.75	6
1.75-1.90	7
1.90-2.10	8
2.10-2.36	9

According to the criteria ratios in Table 3.6, importance levels were determined and a pairwise comparison matrix was created. After the pairwise comparison matrix was created, the column total values of each column was calculated. Table 3.8 shows the pairwise comparison matrix and column totals between the criteria. By dividing the value in each column of the pairwise comparison matrix by the column total value, the normalized values of the criteria, which are free from measurement units, was obtained. Table 3.9 shows the normalized values.

Table 3.8 : Pairwise comparison matrix between criteria.

Criteria	C1	C2	C3	C4	C5	C6
C1: Operat. ease of use and less training requir. prior to use	1.000	0.500	0.250	6.000	0.250	4.000
C2: No chemical handling requirement	2.000	1.000	0.333	7.000	0.333	5.000
C3: Rare alarms and malfunctions	4.000	3.000	1.000	9.000	2.000	8.000
C4: No preparation requirement prior to ballast operation	0.167	0.143	0.111	1.000	0.111	0.333
C5: Easy maintenance	4.000	3.000	0.500	9.000	1.000	7.000
C6: Small footprint of the system and easy routine controls	0.250	0.200	0.125	3.000	0.143	1.000
Column Total	11.417	7.843	2.319	35.000	3.837	25.333

Table 3.9 : Normalized matrix.

Criteria	C1	C2	C3	C4	C5	C6
C1: Operat. ease of use and less training requir. prior to use	0.088	0.064	0.108	0.171	0.065	0.158
C2: No chemical handling requirement	0.175	0.128	0.144	0.200	0.087	0.197
C3: Rare alarms and malfunctions	0.350	0.383	0.431	0.257	0.521	0.316
C4: No preparation requirement prior to ballast operation	0.015	0.018	0.048	0.029	0.029	0.013
C5: Easy maintenance	0.350	0.383	0.216	0.257	0.261	0.276
C6: Small footprint of the system and easy routine controls	0.022	0.026	0.054	0.086	0.037	0.039

Importance levels were obtained by averaging the rows of the matrix consisting of normalized values. The importance levels are shown in Table 3.10.

Table 3.10 : Relative importance levels of criteria.

Criteria	Importance levels
C1: Operational ease of use and less training requirement prior to use	0.1089
C2: No chemical handling requirement	0.1551
C3: Rare alarms and malfunctions	0.3764
C4: No preparation requirement prior to ballast operation	0.0252
C5: Easy maintenance	0.2904
C6: Small footprint of the system and easy routine controls	0.0440

When the importance levels are examined, it is seen that the most effective criterion in BWT system method evaluation is “rare alarms and malfunctions”. It is seen that the second important criterion is " easy maintenance ". The importance of the criteria “no preparation requirement prior to ballast operation” and “small footprint of the system and easy routine controls” is seen as very low.

The consistency ratio of the pairwise comparison matrix should be ≤ 0.1 (Saaty, 1987). To check the comparison matrix made, the consistency ratio was calculated. To calculate the consistency ratio, the rows of the pairwise comparison matrix were multiplied by the importance levels of the criteria and the priorities matrix was formed. Table 3.11 shows the priorities matrix created by multiplying the values in the pairwise comparison matrix by the importance levels of the criteria.

Table 3.11 : Priorities matrix.

Criterions	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Criteria 6
Criteria 1	0.088	0.064	0.108	0.171	0.065	0.158
Criteria 2	0.175	0.128	0.144	0.200	0.087	0.197
Criteria 3	0.350	0.383	0.431	0.257	0.521	0.316
Criteria 4	0.015	0.018	0.048	0.029	0.029	0.013
Criteria 5	0.350	0.383	0.216	0.257	0.261	0.276
Criteria 6	0.022	0.026	0.054	0.086	0.037	0.039

All rows obtained in Table 3.11 were summed separately and divided by the importance levels of the criteria. After division, all values obtained were summed and divided by the number of criteria. As a result of this process, λ was obtained. After λ was obtained, indicator of consistency was calculated. The calculated indicator of consistency value was divided by the number of random index to obtain the consistency ratio. Table 3.12 shows the stages of calculating the consistency ratio value.

Table 3.12 : Calculating the consistency ratio for the criteria.

Criterions	Row total	Importance levels	Row total/Importance levels
Criteria 1	0.6804	0.1089	6.245899
Criteria 2	0.9916	0.1551	6.393211
Criteria 3	2.4370	0.3764	6.475107
Criteria 4	0.1543	0.0252	6.114188
Criteria 5	1.9144	0.2904	6.591922
Criteria 6	0.2664	0.0440	6.062173
λ= 6.313750		CI= 0.062750	CR= 0.050605

Since the CR value was less than ≤ 0.10, the determined pairwise comparison matrix was found to be consistent.

After it was seen that there was no inconsistency in the importance levels of the criteria, pairwise comparisons of El-Chem and UV type BWT systems were made according to the criteria. The ratios used in these comparisons were extracted from the survey results. Each of the criteria was asked to the experts participating in the survey separately for UV and El-Chem systems. According to the survey results, the average scores of both BWT systems are shown in Table 3.13.

Table 3.13: Scores of UV and El-Chem systems according to the survey results.

Criterions	El-Chem	UV	Ratio
Operational ease of use and less training requirement prior to use	2.595	3.830	1.476
No chemical handling requirement	1.700	4.400	2.588
Rare alarms and malfunctions	1.810	3.26	1.801
No preparation requirement prior to ballast operation	2.190	3.69	1.685
Easy maintenance	2.350	3.67	1.562
Small footprint of the system and easy routine controls	2.605	3.75	1.44

After calculating the ratios of the criteria according to the alternatives, the pairwise comparison matrix of the alternatives was created. By dividing the generated comparison matrix values by the row sum, the importance weights of the criteria for both BWT systems were calculated. Table 3.14 - Table 3.19 show pairwise comparisons of UV and electrochemical methods.

Table 3.14 : Evaluation of the criterion operational ease of use and less training requirement prior to use among alternatives.

Alternatives	UV	El-Chem
UV	1	1.476
El-Chem	0.678	1
Row Total	1.678	2.476
Importance weight	0.596	0.404

Table 3.15 : Evaluation of no chemical handling requirement criterion among alternatives.

Alternatives	UV	El-Chem
UV	1	2.588
El-Chem	0.386	1
Row Total	1.386	3.588
Importance weight	0.721	0.279

Table 3.16 : Evaluation of rare alarms and malfunctions criteria among alternatives.

Alternatives	UV	El-Chem
UV	1	1.801
El-Chem	0.555	1
Row Total	1.555	2.801
Importance weight	0.643	0.357

Table 3.17 : Evaluation of no preparation requirement prior to ballast operation criterion among alternatives.

Alternatives	UV	El-Chem
UV	1	1.685
El-Chem	0.593	1
Row Total	1.593	2.685
Importance weight	0.628	0.372

Table 3.18 : Evaluation of the criterion to be easy of maintenance among alternatives.

Alternatives	UV	El-Chem
UV	1	1.562
El-Chem	0.640	1
Row Total	1.640	2.562
Importance weight	0.610	0.390

Table 3.19: Evaluation of small footprint of the system and easy routine controls criterion among alternatives.

Alternatives	UV	El-Chem
UV	1	1.440
El-Chem	0.694	1
Row Total	1.694	2.440
Importance weight	0.590	0.410

In order to calculate the result of the AHP, the importance level of the criteria (Table 3.9) and the importance weights of each of the alternatives for that criterion are multiplied. The result obtained shows the holistic importance value among the alternatives.The result of the obtained AHP technique is shown in Figure 3.3.

This AHP application, based on a survey of expert seafarers, shows that UV systems are 1.76 times more preferred than electrochemical systems based on the experience of expert seafarers.

Although the maritime company's twin ships built in 2015 were equipped with an electrochemical BWT system, the integration of UV systems on two new-built ships in 2019 is in line with the preferences of seafarers according to the AHP method, which was created as a result of the opinions of the experts working on the ship of this company.

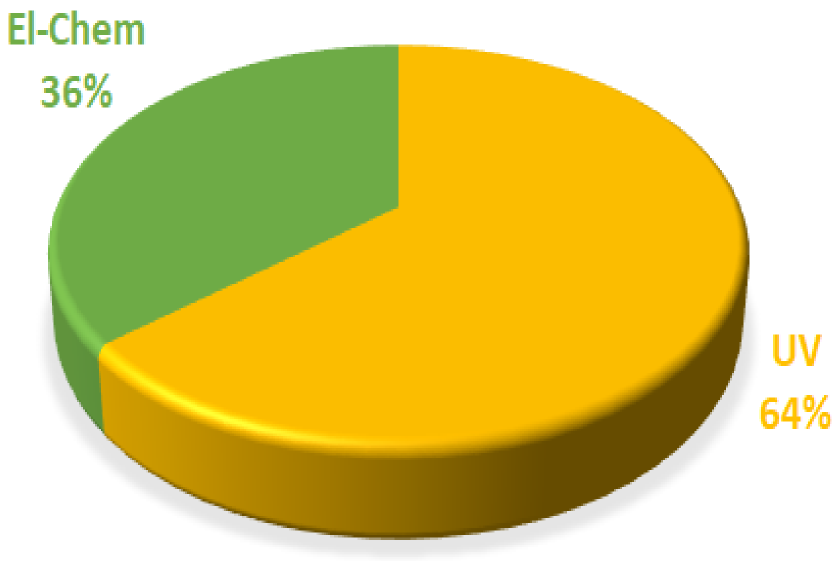

Figure 3.3 : Evaluation of UV and El-Chem methods from the eyes of expert seafarers.

3.2 The Background of the Study and Data Gathering for BWTS Brand Evaluation

The maritime company has integrated UV-2 brand BWT systems in 2021 on two different tonnage tanker ships built before 2013. In order to evaluate two different brands of the same type, ten expert seafarers who worked on both UV-1 and UV-2 brands were interviewed. Three of the interviewed seafarers have the license of oceangoing master and seven of them have the license of oceangoing chief engineer. As a result of the interviews, the general opinions obtained for both brands are as follows:

- When the mechanical filters of UV-1 brand and UV-2 brand are compared, it is seen that the filter of UV-2 brand is much larger in ships with the same capacity. The biggest disadvantage of the larger filter is that it is more difficult to maintain. UV-1 brand is smaller in size and easier to maintain in terms of the filter system used.
- UV-2 brand uses electrically controlled valves on the system while UV-1 brand uses pneumatically controlled valves. Pneumatically controlled valves may experience jamming due to the water in the air. In addition, the on-off operation of pneumatically controlled valves is more difficult than electrically controlled valves. The fact that the UV-2 system has electrically controlled valves is an advantage for seafarers.

- The display software of the UV-1 system is more complex than the UV-2 system. The screen software of the UV-2 system is simpler and easier to understand.
- The remote operation screen of UV-1 and UV-2 system is usually located in the cargo control room of tanker ships. In cases where the ship's air conditioning system is inadequate, especially the UV-2 system's operation screen freezes and the system needs to be restarted. Frequent occurrence of this situation may damage the system software. It also causes the ballast-deballast operation to stop for a short period of time.
- The UV-1 system has a special cleaning system to clean the UV reactor. This special cleaning system increases the efficiency of the UV reactor, allowing it to consume less energy.
- UV-2 system has more UV lamp failures than UV-1 system. UV lamp replacement during the operation also affects the cargo loading-unloading operation.
- The sensors (temperature, pressure, etc.) used in the UV-1 system measure more accurately than the UV-2 system and experience fewer failures.
- Due to the lack of a wide spare parts and service network for the UV-2 system, it takes much longer to obtain spare parts.
- The memory card of the UV-2 system can reset the data in it due to the temperature of the room where it is located. Past operations of the BWT system cannot be checked if 3rd party persons come on board.
- UV-1 system has a wide service network worldwide. In case of a possible malfunction, spare parts or information request, a solution is reached quickly.
- The user manual and all documents of the UV-1 system are more understandable than the UV-2 system.

All seafarers who participated in the survey were asked which brand of BWT system would you prefer to work with. Table 3.20 shows the brands preferred by the surveyed expert seafarers.

Table 3.20 : BWT brand preferences of expert seafarers.

BWTS Brand	Deck Officer Score	Engine Officer Score	Total Score
UV-1	14	19	33
Other Brands	10	7	17

All seafarers who participated in the survey were asked which brand of BWT system they would prefer to work with. 66% of the seafarers preferred UV-1 brand. The reasons for the preference of the UV-1 brand are less alarms and malfunctions, ease of use and maintenance, wide international technical service support, easy supply of spare parts and the confidence that the brand has been recognized in the maritime market for many years.

In 2021, the equipment price, installation cost and 10-year operational costs of UV-1 and UV-2 brand BWT systems for a total of two ships were learned during the interviews with the maritime company that chose BWT systems for their ships. Table 3.21 shows the general costs of UV-1 and UV-2 brands for a total of two ships.

Table 3.21 : Costs of UV-1 and UV-2 brand BWT systems.

BWTS Brand	Equipment Cost (€)	Installation Cost(€)	Operation Cost (10 years) (€)	Total Cost (€)
UV-1	690.000	550.000	594.818	1.834.818
UV-2	509.340	550.000	399.730	1.459.070

3.2.1 Determining criteria for AHP

In the light of the data obtained as a result of the bilateral interviews, six different criteria were determined to evaluate two different brands of BWT systems with AHP method. The six criteria are respectively;

- Criterion 1- Proper operation of remote controlled valves: The open-close actuators of the remote controlled valves used in the BWT system is air, oil or electrically driven. Especially in systems with air actuators, the moisture-water in the air causes the valve to jam.In systems with poor quality valve actuators, if the valves get stuck, the ballast operation cannot be started or if it occurs during the ballast operation, it causes the system to stop completely.

- Criterion 2- Rare alarms and malfunctions: This criterion is explained in detail in section 3.1.1.1.
- Criterion 3- Operational ease of use and less training requirement prior to use: This criterion is explained in detail in section 3.1.1.1.
- Criterion 4- Easy maintenance: This criterion is explained in detail in section 3.1.1.1.
- Criterion 5- International technical service and spare parts supply: The wide worldwide service network of the ballast water treatment system to be selected minimizes the loss of time that may be experienced when there is a malfunction that cannot be solved by ship crew. The fact that the system manufacturer has an international service network is an advantageous situation for both seafarers and ship owners. In addition, in the event of a possible malfunction, the rapid supply of the necessary spare parts to the ship relieves the ship owners and ship crew.
- Criterion 6- High quality of the equipments used: It is very important that all equipment used in BWT systems such as mechanical filters, temperature gauges, flowmeters, pressure gauges, software and computer systems are of high quality. Poor quality filter elements are seen to break down over time and enter the UV reactor, thus damaging the UV reactor. There are many negativities during operation such as late response of the software systems used and freezing of the computer system depending on the ambient temperature. During the operation, it is observed that the filter element is self-cleaning without stopping, especially as a result of incorrect measurement of the mechanical filter inlet and outlet pressure elements. As it is known, while the filters are cleaning themselves, the capacity of the treated ballast water decreases. Therefore, the negativities caused by the use of poor quality materials directly affect the ballast operation.

3.2.2 Evaluation of BWTS brand with application of AHP

After the alternatives and criteria were determined, a hierarchical structure was created for the application of the AHP technique for BWTS brand evaluation. Figure 3.4 shows the hierarchical structure of the AHP method to be applied.

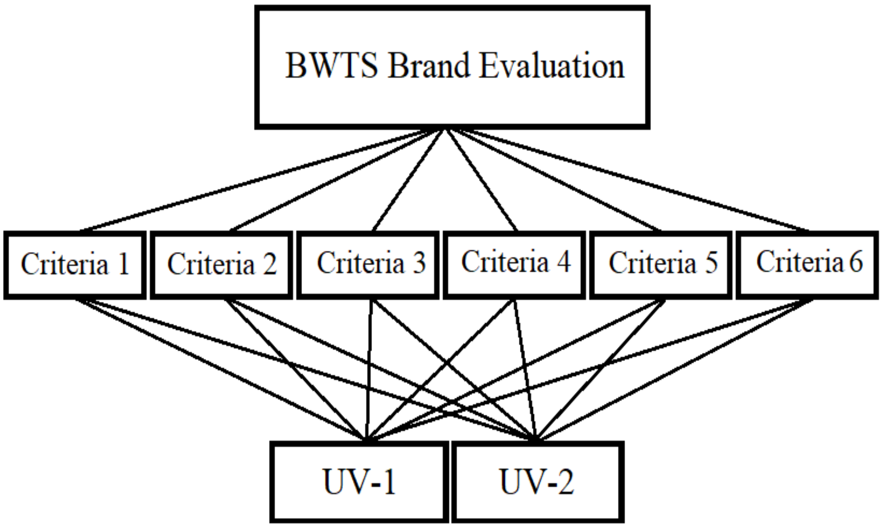

Figure 3.4 : Hierarchical structure of BWTS brand evaluation.

Although the criteria were determined by taking the opinions of expert seafarers, the value of each criterion is different according to each seafarer's point of view. Therefore, seafarers were asked to rank these six criteria in order to determine the criteria's importance levels. In the light of the assessments of the seafarers, the pairwise comparison matrix in Table 3.22 was obtained. Table 3.23 shows the normalized values.

Table 3.22 : Pairwise comparison matrix between criteria.

Criteria	C1	C2	C3	C4	C5	C6
C1: Proper operation of remote controlled valves	1.000	0.143	2.000	0.500	0.333	0.167
C2: Rare alarms and malfunctions	7.000	1.000	9.000	5.000	3.000	2.000
C3: Oper. ease of use and less train. requir. prior to use	0.500	0.111	1.000	0.250	0.200	0.125
C4: Easy maintenance	2.000	0.200	4.000	1.000	0.500	0.250
C5: International tech. service and spare parts supply	3.000	0.333	5.000	2.000	1.000	0.500
C6: High quality of the equipments used	6.000	0.500	8.000	4.000	2.000	1.000
Column Total	19.500	2.287	29.000	12.750	7.033	4.042

Table 3.23: Normalized matrix.

Criteria	C1	C2	C3	C4	C5	C6
C1: Proper operation of remote controlled valves	0.051	0.062	0.069	0.039	0.047	0.041
C2: Rare alarms and malfunctions	0.359	0.437	0.310	0.392	0.427	0.495
C3: Oper. ease of use and less train. requir. prior to use	0.026	0.049	0.034	0.020	0.028	0.031
C4: Easy maintenance	0.103	0.087	0.138	0.078	0.071	0.062
C5: International tech. service and spare parts supply	0.154	0.146	0.172	0.157	0.142	0.124
C6: High quality of the equipments used	0.308	0.219	0.276	0.314	0.284	0.247

Importance levels are obtained by averaging the rows of the matrix consisting of normalized values. The importance levels are shown in Table 3.24.

Table 3.24 : Relative importance levels of criteria.

Criteria	Importance levels
C1: Proper operation of remote controlled valves	0.0518
C2: Rare alarms and malfunctions	0.4033
C3: Operational ease of use and less training requir. prior to use	0.0313
C4: Easy maintenance	0.0899
C5: International technical service and spare parts supply	0.1491
C6: High quality of the equipments used	0.2746

When we examine the importance levels, the most important criterion for BWT system brand evaluation is "rare alarms and malfunctions". The second most important criterion is the high quality of the equipment used. Proper operation of remote controlled valves, ease of use and requiring little training were seen as the least important criteria.

The consistency ratio of the pairwise comparison matrix should be ≤ 0.1 (Saaty, 1987). To check the comparison matrix made, the consistency ratio must be calculated. To calculate the consistency ratio, the rows of the pairwise comparison matrix are multiplied by the importance levels of the criteria and the priorities matrix is formed. Table 3.25 shows the priorities matrix created by multiplying the values in the pairwise comparison matrix by the importance levels of the criteria.

Table 3.25 : Priorities matrix.

Criterions	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Criteria 6
Criteria 1	0.052	0.058	0.063	0.045	0.050	0.046
Criteria 2	0.362	0.403	0.282	0.449	0.447	0.549
Criteria 3	0.026	0.045	0.031	0.022	0.030	0.034
Criteria 4	0.104	0.081	0.125	0.090	0.075	0.069
Criteria 5	0.155	0.134	0.156	0.180	0.149	0.137
Criteria 6	0.311	0.202	0.250	0.360	0.298	0.275

All rows obtained in Table 3.25 were summed separately and divided by the importance levels of the criteria. After division, all values obtained were summed and divided by the number of criteria. As a result of this process, λ was obtained. After λ was obtained, indicator of consistency was calculated. The calculated indicator of consistency value was divided by the number of random index to obtain the consistency ratio. Table 3.26 shows the stages of calculating the consistency ratio value.

Table 3.26: Calculating the consistency ratio for the criteria.

Criterions	Row total	Importance levels	Row total/Importance levels
Criteria 1	0.3124	0.0518	6.034877
Criteria 2	2.4932	0.4033	6.181292
Criteria 3	0.1886	0.0313	6.029525
Criteria 4	0.5424	0.0899	6.034367
Criteria 5	0.9123	0.1491	6.117825
Criteria 6	1.6949	0.2746	6.171848
λ= 6.094956		CI= 0.018991	CR= 0.015315

Since the CR value is less than ≤ 0.10, the determined pairwise comparison matrix was found to be consistent.

After calculating the ratios of the criteria according to the alternatives, the pairwise comparison matrix of the alternatives was created. By dividing the generated comparison matrix values by the row sum, the importance weights of the criteria for both BWT systems were calculated. Table 3.27 - Table 3.32 show pairwise comparisons of UV-1 and UV-2 brands.

Table 3.27 : Evaluation of proper operation of remote controlled valves criterion among alternatives.

Alternatives	UV-1	UV-2
UV-1	1.000	0.500
UV-2	2.000	1.000
Row Total	3.000	1.500
Importance weight	0.333	0.667

Table 3.28 : Evaluation of rare alarms and malfunctions criterion among alternatives.

Alternatives	UV-1	UV-2
UV-1	1.000	1.500
UV-2	0.667	1.000
Row Total	1.667	2.500
Importance weight	0.600	0.400

Table 3.29 : Evaluation of operational ease of use and less training requirement prior to use criterion among alternatives.

Alternatives	UV-1	UV-2
UV-1	1.000	0.714
UV-2	1.400	1.000
Row Total	2.400	1.714
Importance weight	0.417	0.583

Table 3.30 : Evaluation of easy maintenance criterion among alternatives.

Alternatives	UV-1	UV-2
UV-1	1.000	1.400
UV-2	0.714	1.000
Row Total	1.714	2.400
Importance weight	0.583	0.417

Table 3.31 : Evaluation of international technical service and spare parts supply criterion among alternatives.

Alternatives	UV-1	UV-2
UV-1	1.000	1.500
UV-2	0.667	1.000
Row Total	1.667	2.500
Importance weight	0.600	0.400

Table 3.32 : Evaluation of high quality of the equipments used criterion among alternatives.

Alternatives	UV-1	UV-2
UV-1	1.000	1.500
UV-2	0.667	1.000
Row Total	1.667	2.500
Importance weight	0.600	0.400

In order to calculate the result of the AHP, the importance level of the criteria (Table 3.21) and the importance weights of each of the alternatives for that criterion are multiplied. The result obtained shows the holistic importance value among the alternatives. The result of the obtained AHP technique is shown in Figure 3.5.

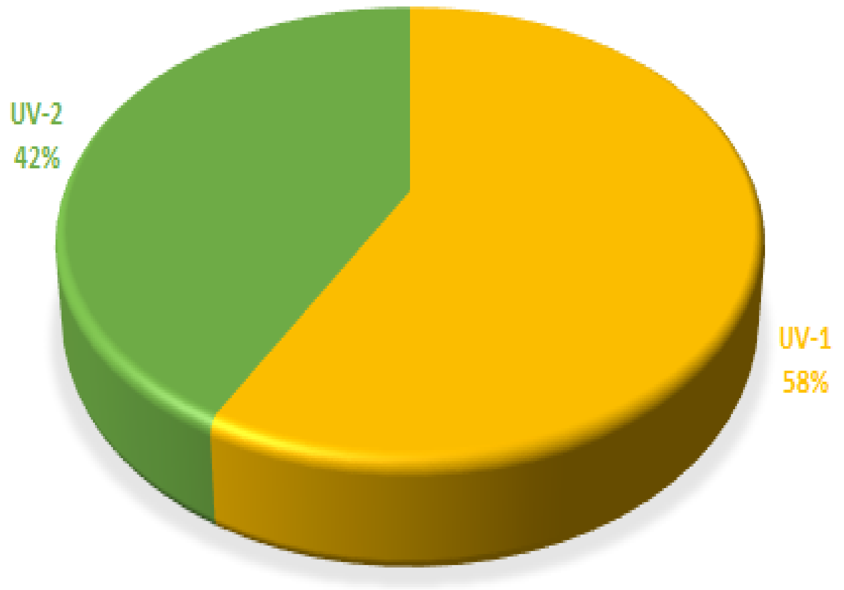

Figure 3.5 : Evaluation of UV-1 and UV-2 brands from the eyes of expert seafarers.

This AHP application, based on a survey of expert seafarers, shows that the UV-1 brand is preferred 1.38 times more than the UV-2 brand based on the experience of expert seafarers. Although the maritime company preferred UV-1 brand BWT system for two tanker vessels of the same tonnage built in 2019, it preferred UV-2 brand for two existing vessels in 2021. According to the AHP technique created as a result of the opinions of expert seafarers working in both brands of BWT systems, the choice of UV-2 brand is not in line with the opinions of the experts.

4. CONCLUSIONS

According to the BWM Convention, ships must have a type-approved BWT system to meet the D-2 standard. In today's maritime market, there are many different brands and types of BWT systems that meet the D-2 standard. Ship owners should pay attention to the qualitative criteria of the equipment as well as the installation and operating costs during the BWTS selection phase.

Since BWT systems have been in use especially in the last five and a half years, maritime companies take into consideration some specified criteria in the BWTS selection process. After the equipment started to be used, seafarers started to gain knowledge and experience about BWT systems. These experiences gained by seafarers have enabled maritime companies to have information about the equipment.

UV and El-Chem type BWT systems are generally used on ships. In order to determine the features that a BWT system should have, expert seafarers who use these systems on ships were interviewed. In addition, the failure reports written about the BWT systems of the maritime company, which has integrated El-Chem, UV-1 and UV-2 systems to its ships in its fleet since 2015, were examined. As a result of the bilateral interviews, it was observed that the use of chemicals, alarm and malfunction situations and the need for preliminary preparation for the operation were among the features that made the system difficult to be preferred to work with. On the other hand, the ease of use and maintenance of the system, the fact that the system contains few components and takes up little space in total, the ease of routine checks, and the fact that it requires less training before use are among the prominent features for the systems to be preferred by seafarers.

Since the priorities of each seafarer may differ, seafarers were asked to prioritize these features through a questionnaire prepared on Google Forms. This questionnaire was sent to deck and engine officers separately to determine the differences in the opinions of two different departments working on board.

As it is known, deck officers are responsible for the operation of BWT systems and engine officers are responsible for the maintenance. The reasons why the majority of engine officers prefer UV systems are that the maintenance of UV systems is simpler than El-Chem systems and does not involve chemical handling.

All seafarers who participated in the survey were asked which brand of BWT system they would prefer to work with. 66% of the seafarers preferred UV-1 brand. The reasons for the preference of the UV-1 brand are less alarms and malfunctions, ease of use and maintenance, wide international technical service support, easy supply of spare parts and the confidence that the brand has been recognized in the maritime market for many years.

Although 8 basic features were identified in this study, it was determined that the priority order and importance of these features differed in the system preference of each expert seafarer. AHP method was utilized in order to reach a general evaluation based on the experiences of seafarers regarding the use of the systems on board. These 8 basic features were identified into 6 criteria (i.e., Operational ease of use and less training requir. prior to use, No chemical handling requirement, Rare alarms and malfunctions, No preparation requirement prior to ballast operation, Easy maintenance, Small footprint of the system and easy routine controls). The importance ranking of these criteria was determined by taking into account the responses of the seafarers to the questionnaire, bilateral interviews and failure records. The purpose of the importance ranking is to obtain the pairwise comparison matrix values of the criteria to be used for the application of the AHP technique and to determine the expectations of the seafarers from the BWT system. The most important of the eight different features, which were determined by the common scores of all seafarers participating in the survey, are low alarms and malfunctions of the BWT system, ease of use, ease of maintenance and no chemical handling. When we analyze the survey results for two different departments working on board, the most important feature for the engine department crew is ease of maintenance while for the deck department, it is ease of use. The least important feature for all seafarers surveyed is that the BWT system requires preparation before ballast operation. When we analyze the engine department, we see that the least important feature is the need for little training in the use of the BWT system, while for the deck department, we see that the equipment takes up little space and is simple. The reason why the departments think differently from each other is that since it is the deck officers who use the system, it is not important for the engine officers to require little training before use. The fact that the system is particularly simple and plain is not important for deck officers as it directly affects the maintenance of the equipment.

According to the AHP technique applied based on the opinions of expert seafarers, it is concluded that UV type BWT system is 1.76 times more preferable than El-Chem type BWT system. According to this result, the maritime company that preferred the UV-1 system for two tanker ships of the same tonnage built in 2019 made a decision in line with the opinions of expert seafarers.

Although electrochemical systems produce disinfection chemicals on board, extra chemicals are still needed for both TRO control and system maintenance, and chemical use may be the most significant disadvantage of El-Chem type BWT systems for mariners. Because chemical handling is always a risk for seafarers. Despite the presence of all personal protective equipment on board in case of chemical handling, seafarers always react negatively to the use of chemicals. In addition, El-Chem type BWT systems are more complex system than UV systems. Therefore, maintenance of El-Chem type BWT systems is more difficult for ship personnel.

In order to evaluate two different brands of UV systems (UV-1 and UV-2), expert seafarers who worked in both brands of UV systems were interviewed. After the bilateral interviews, the positive and negative features of both brands of BWT systems against each other were determined. Then, six different criteria were determined for the evaluation of both brands of BWT systems with the AHP technique. The pairwise comparison matrix values of the six criteria were determined in the light of the data obtained from the interviews with the expert seafarers. As a result of the interviews, the most important features that a UV type BWT system should have been low alarms and malfunctions, quality of the equipment used and international technical service and spare parts supply.

According to the AHP technique applied based on the opinions of expert seafarers, it is concluded that UV-1 brand BWT system is 1.38 times more preferable than UV-2 brand BWT system. According to this result, the maritime company that preferred UV-2 system for two existing tanker ships of different tonnage in 2021 made a decision that is not in line with the opinions of expert seafarers.

According to the information obtained during the bilateral meetings with the maritime company officials, it was learned that the main reason for the selection of UV-2 brand BWT system is that the operational and installation costs are approximately 26% more affordable than UV-1 brand. Expert seafarers who have been working with UV-2 brand for about 2 years point out that UV-2 brand has more frequent breakdowns compared to UV-1 brand. Each failure in the system causes the ballast operations to stop and therefore the ship's stay in port may be prolonged. In addition, more alarms occur as a result of incorrect measurement of temperature, pressure, etc. indicators used in UV-2 brand BWT systems. Especially during cargo loading on tanker ships, this situation may cause distraction of the officers in charge of the cargo and cause bigger problems.

It is important that the manufacturer of a BWT system, which meets certain conditions and is considered economically viable, is available at least as long as the life of the ship. Especially for ships sailing internationally, if spare parts supply and international service support cannot be provided quickly, the commercial activity of the ship may be damaged.

Considering that the life span of a ship is approximately 30 years, maritime companies should decide on BWT system selection based on 30 years. Although installation and operation costs are an important selection criterion, it is very important to choose a BWT system that uses quality materials, has a wide international technical service network, can quickly provide online support for problems, provides fast spare parts supply and has strong references in order to prevent damage to commercial activity.

If ship owners choose a BWT system by prioritizing financial concerns during the selection phase of BWT systems, it may cause more financial losses in the long term.

Until recently, the selection of ballast water treatment systems was based on a predetermined set of criteria and there was no experience on board. With the entry into force of the Ballast Water Management Convention, on-board experiences are also being developed. Among these, the experiences and evaluations of the expert seafarers responsible for the use of the systems on ships will be of great importance. This study was completed by evaluating the 5-year experiences and opinions of 50 expert seafarers working in a Turkish maritime company in order to contribute to the selection processes.

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