VOLUME 7, ISSUE 2 (2019)

UCTEA - The Chamber of Marine Engineers

JEMS

JOURNAL OF ETA MARITIME SCIENCE

Yavuz, B. R. (2017) Passage in the Strait of Istanbul, TURKEY.

JEMS - JOURNAL OF ETA MARITIME SCIENCE - ISSN: 2147-2955

ISSN:2147-2955

Volume : 7
Issue : 2
Year : 2019

JEMS JOURNAL

Journal of ETA Maritime Science

JOURNAL INFO

Publisher : **Feramuz AŞKIN**
The Chamber of Marine Engineers Chairman of the Board

Engagement Manager : Alper KILIÇ

Typesetting : Emin Deniz ÖZKAN
Burak KUNDAKÇI
Ömer ARSLAN
Coşkan SEVGİLİ

Layout : Remzi FIŞKIN
Cover Design : Selçuk NAS
Cover Photo : Burak Reis YAVUZ

Publication Place and Date :

The Chamber of Marine Engineers
Address : *Sahrayıcedit Mah. Halk Sk. Golden Plaza No: 29 C Blok K:3 D:6 Kadıköy/İstanbul - Türkiye*
Tel : *+90 216 747 15 51*
Fax : *+90 216 747 34 35*

Online Publication : www.jemsjournal.org / 30.06.2019

ISSN : 2147-2955
e-ISSN : 2148-9386

Type of Publication: JEMS is a peer-reviewed journal and is published quarterly (March/June/September/December) period.

Responsibility in terms of language and content of articles published in the journal belongs to the authors.

JEMS JOURNAL

EDITORIAL BOARD

JEMS JOURNAL

EDITORIAL BOARD

JEMS JOURNAL

MEMBERS OF ADVISORY BOARD:

JEMS JOURNAL

JEMS SUBMISSION POLICY:

1. Submission of an article implies that the manuscript described has not been published previously in any journals or as a conference paper with DOI number.
2. Submissions should be original research papers about any maritime applications.
3. It will not be published elsewhere including electronic in the same form, in English, in Turkish or in any other language, without the written consent of the copyright-holder.
4. Articles must be written in proper English language or Turkish language.
5. It is important that the submission file to be saved in the native format of the template of word processor used.
6. References of information must be provided.
7. Note that source files of figures, tables and text graphics will be required whether or not you embed your figures in the text.
8. To avoid unnecessary errors you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your word processor.
9. JEMS operates the article evaluation process with "double blind" peer review policy. This means that the reviewers of the paper will not get to know the identity of the author(s), and the author(s) will not get to know the identity of the reviewer.
10. According to reviewers' reports, editor(s) will decide whether the submissions are eligible for publication.
11. Authors are liable for obeying the JEMS Submission Policy.
12. JEMS is published quarterly period (March, June, September, December).
13. JEMS does not charge any article submission or processing charges.

JEMS JOURNAL

CONTENTS

JEMS JOURNAL

İÇİNDEKİLER

DOI ID: 10.5505/jems.2019.75046

Journal of ETA Maritime Science

JEMS JOURNAL

Editorial (ED)

Autonomous Ships from the Editor's Perspective

The number of computer-aided systems on boards is gradually increasing and the number of people on board is decreasing as a result of the technological development. For example, a cargo ship with a crew of 20-25 people can now safely operate with fewer people. While speaking about the technological development, it is appropriate to underline two concepts: big data and the internet of things (IoT). Big data is briefly defined as the emergence of reliable new information, depending on how much information having about anything. The IoT is defined as a network where objects can connect to each other or to larger systems. These two concepts take technological development to a different level and play a major role especially in the development of autonomous systems. We can say that autonomous and remotely controlled ship technology also emerged on the basis of these two concepts.

The concept of autonomous ship includes fundamental technologies such as autonomous navigation, automatic berthing / unberthing, remotely-monitored engine, equipment and loading operations and automatic communication between ships. It covers a wide range from ships which are fully unmanned or can be remotely-controlled from land-based virtual bridges, and ships with systems that alert the operator to a possible pre-conflict or help optimize operations.

Although the idea that ships could sail with computer support was originally based on the 1970s, research has gained momentum especially since the beginning of 2010s. The first unmanned surface vehicle project launched by South Korea in 2011 and the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project launched in 2012 and financed by the European Union emerged as the first concrete steps. New developments about the topic are experienced day by day in the international arena with the lead of the United States of America (USA), United Kingdom (UK), China, Denmark, Finland, South Korea, Japan, Norway and Singapore. While the governmental institutions make efforts especially on the establishment of legal regulations and standards, private institutions carry out studies on technological development. For example, UK Maritime Autonomous Systems Regulatory Working Group (MASRWG) has developed a code of conduct for autonomous ships. Norway has established the Norwegian Forum for Autonomous Ships (NFAS) to support and develop the concept of unmanned maritime transport with the participation of government agencies and industrial organizations. On the other hand, the Chinese Classification Society (CSS), ClassNK and DNV GL have initiated studies to set standards and to make recommendations for the revision of international regulations. From the private organizations, especially Rolls-Royce, Google, Intel, Norway-based Yara and Kongsberg, Finland-based FinFries and Mitsui O.S.K. Lines (MOL) spends effort to develop the technology. In addition to the consortiums established by governments and companies alone or together, There is an international group established to strengthen the relationship network between organizations interested in the field of autonomous and unmanned ships research. The group, called the International Network for Autonomous Ships (INAS) and whose secretariat is run by Norway, consists of 16 countries including USA, UK, China, Denmark, Finland, South Korea, Japan and Australia and European Space Agency (ESA) and the European Maritime Safety Agency (EMSA). From the Turkey perspective, Dokuz Eylul University, İstanbul Technical University and Yıldız Technical University conducts research on the subject and companies such as ASELSAN and SANMAR are working on the subject.

It is predicted that the autonomous or remotely controlled ships may commence operations sooner than expected due to the rapid development of the technology. IMO has taken the issue to its agenda taking this possibility into consideration. The 98th meeting (MSC 98) held by the IMO Maritime Safety Committee (MSC) in June 2017 is the first committee meeting in which the concept of unmanned and autonomous ships came to the agenda. In the meeting, which was taking into consideration the rapid development of unmanned vessels in the future, it was suggested that the requirements of Maritime Autonomous Surface Ships (MASS) should be investigated under the headings of safety, security, environment and efficiency and discussed on revision of existing regulations. As a result of the MSC 98, it was decided that a work program should be initiated at the next meeting to define an "autonomous ship" definition and a regulatory scope on existing IMO regulations. At the 99th committee meeting (MSC 99) held in May 2018, the committee initiated a study on how safe, secure and environmentally sensitive MASS operations can be conducted. At this meeting, the Committee approved the methodology and work plan for the regulatory scoping study, which includes details such as the MASS definition and autonomous degrees. MASS was defined by the Committee as "a vessel capable of operating independently of varying degrees of human interaction". At the 100th meeting (MSC 100) held in December 2018, the committee completed the first regulatory scoping activities for autonomous ships. IMO instruments to be discussed within the scope of the scoping exercise planned to be completed in 2020 include safety, watchkeeping standards, search and rescue, security, traffic rules, loading and ship balance. The committee also initiated a working group to establish guidelines for the testing of autonomous ships.

As a result, the concept of autonomous and unmanned ships may be the hottest research topic in the maritime industry, nowadays. International institutions and organizations intensively carry out their initiatives and activities in order to gain competitive advantage in this new field. Turkey needs to be active not to miss the rapid progress in autonomous ship technology. Similar to the international activities mentioned above, launching some initiatives in Turkey is extremely important in terms of having a significant pie-share of the new technology in the future. Forming a research group consisting of universities, government agencies and private organizations and taking an active role as a member of international associations such as the INAS will contribute to be among the countries producing technologies for autonomous ship concept. As an editorial board, we plan to include more frequently the studies on autonomous ships and artificial intelligence applications in JEMS.

Editor
Prof. Dr. Selçuk NAS
Associate Editor
Remzi Fışkın

Journal of ETA Maritime Science

JEMS JOURNAL

Editörden (ED)

Editör Perspektifinden Otonom Gemiler

Teknolojik gelişim ile birlikte gemilerde yer alan bilgisayar destekli sistem sayısı giderek artmakta ve bu duruma bağlı olarak gemide bulunan insan sayısı kademeli olarak azalmaktadır. Örneğin önceleri 20-25 kişi arası mürettebat bulunduran bir yük gemisi artık çok daha az kişi ile operasyonlarını emniyetli bir şekilde yürütebilmektedir. Teknolojik gelişim demişken burada iki kavramın altını çizmek yerinde olacaktır: büyük veri (big data) ve nesnelerin interneti (internet of things - IoT). Büyük veri kısaca, herhangi bir şey hakkında ne kadar çok bilgi sahibi olunduğuna bağlı olarak güvenilir yeni bilgilerin ortaya çıkması olarak tanımlanmaktadır. Nesnelerin interneti ise, nesnelerin birbirleriyle veya daha büyük sistemlerle bağlantı kurabildiği bir iletişim ağı olarak ifade edilmektedir. Bu iki kavram teknolojik gelişimi farklı bir boyuta taşımakta ve özellikle otonom sistemlerin gelişmesinde büyük rol oynamaktadır. Otonom ve uzaktan kontrol edilebilen gemi teknolojisinin de bu iki kavram temelinde ortaya çıktığını söyleyebiliriz.

Otonom ve uzaktan kontrol edilebilen gemi kavramı; otonom seyir, otomatik yanaşma/ayrılma, uzaktan takip edilebilen makine, teçhizat ve yükleme operasyonları ve gemiler arası otomatik haberleşme gibi birçok otomasyon uygulamayı içeren bir alandır. Tamamen insansız veya karatabanlı sanal köprüüstünden uzaktan kontrol edilebilen gemilerden, operatörü olası bir çatışma öncesi uyaran veya operasyonları optimize etmeye yardımcı sistemlere sahip gemilere kadar geniş bir alanı kapsamaktadır.

Gemilerin bilgisayar desteği ile seyir yapabileceği fikri ilk olarak 1970'li yıllara dayansa da, özellikle 2010'lu yılların başından itibaren araştırmalar ivme kazanmıştır. 2011 yılında Güney Kore tarafından başlatılan insansız suüstü aracı projesi ve 2012 yılında başlatılan ve Avrupa Birliği tarafından finanse edilen "Maritime Unmanned Navigation through Intelligence in Networks (MUNIN)" projesi ilk somut adımlar olarak ortaya çıkmıştır. Uluslararası arenada konu üzerine Amerika Birleşik Devletleri (ABD), Birleşik Krallık, Çin, Danimarka, Finlandiya, Güney Kore, Japonya, Norveç, Singapur gibi ülkelerin başı çekmesi ile her geçen gün yeni gelişmeler yaşanmaktadır. Devlet kurumları özellikle yasal düzenlemeler ve standartların belirlenmesi üzerine çaba harcarken, özel kuruluşlar teknolojik olarak gelişimin sağlanması üzerine çalışmalar yürütmektedirler. Örneğin, Birleşik Krallık Deniz Otonom Sistemleri Yasal Düzenleme Çalışma Grubu otonom gemiler için yürütme ve uygulama kodu geliştirmiştir. Norveç ise, devlet kurumları ve sanayi kuruluşları iştiraki ile insansız deniz taşımacılığı kavramını desteklemek ve geliştirmek amacıyla Norveç Otonom Gemiler Forumu kurmuştur. Diğer taraftan China Classification Society (CSS), ClassNK ve DNV GL gibi klas kuruluşları ise standartların belirlenmesi ve uluslararası regülasyonların revizyonu için önerilerde bulunmak amacıyla çalışmalar başlatmıştır. Özel kuruluşlara baktığımızda ise özellikle Rolls-Royce, Google, Intel, Norveç merkezli Yara ve Kongsberg, Finlandiya merkezli FinFerries ve Japonya merkezli Mitsui O.S.K. Lines (MOL) gibi firmalar öne çıkmaktadır. Devletlerin ve firmaların tek başına veya bir araya gelerek oluşturdukları birlikteliklere ek olarak, otonom ve insansız gemiler araştırma alanına ilgi duyan organizasyonlar arasındaki ilişki ağını güçlendirmek amacıyla kurulmuş uluslararası bir yapı bulunmaktadır. Otonom Gemiler için Uluslararası İlişki Ağı (INAS) olarak isimlendirilen ve sekretaryası Norveç tarafından yürütülen bu grup içinde, ABD, Birleşik Krallık, Çin, Danimarka, Finlandiya, Güney Kore, Japonya ve Avustralya gibi ülkelerin de yer aldığı toplam 16 ülke, Avrupa Uzay Ajansı ve Avrupa Deniz Emniyeti Ajansı yer almaktadır. Türkiye özelinde ise Dokuz Eylül Üniversitesi, İstanbul Teknik Üniversitesi ve Yıldız Teknik Üniversitesi'nin konu üzerine araştırmalar yürütmektedir. Diğer taraftan ASELSAN A.Ş. ve SANMAR gibi firmalar da konu üzerine çalışmalar yapmaktadır.

Teknolojinin hızla ilerlemesi ile otonom veya uzaktan kontrol edilebilir gemilerin tahmin edilenden daha yakın zamanda faaliyetlerine başlayabileceği öngörülmektedir. Bu ihtimali göz önünde tutan IMO da konuyu gündemine almıştır. IMO Deniz Emniyeti Komitesi (MSC)'nin Haziran 2017'de gerçekleştirdiği 98. toplantı (MSC 98), insansız ve otonom gemi kavramının gündeme geldiği ilk komite toplantısı olma özelliğini taşımaktadır. Ortaya çıkan hızlı gelişimin dikkate alındığı toplantıda, otonom gemiler (Maritime Autonomous Surface Ships - MASS) ile ilgili emniyet, güvenlik, çevre ve verimlilik başlıkları altında gereklerin araştırılması ve mevcut düzenlemelerin revizyonu üzerine tartışılması gerektiği ileri sürülmüştür. MSC 98 sonucunda, "otonom gemi" tanımı ve mevcut IMO düzenlemeleri üzerine düzenleyici bir kapsam belirlenmesi için bir sonraki toplantıda bir çalışma programının başlatılması gerektiğine karar verilmiştir. Mayıs 2018'de gerçekleştirilen 99. toplantıda (MSC 99) ise komite, MASS operasyonlarının ne kadar emniyetli, güvenli ve çevreye duyarlı olarak gerçekleştirilebileceği üzerine bir çalışma başlatmıştır. Komite bu toplantıda, MASS tanımı ve otonom dereceleri gibi detayları da içeren düzenleyici kapsam belirleme çalışması için oluşturulan metodoloji ve çalışma planını onaylamıştır. Komite tarafından MASS "değişken derecelerde insan etkileşiminden bağımsız olarak faaliyet gösterebilen bir gemi" olarak tanımlanmıştır. Aralık 2018'de gerçekleştirilen 100. toplantıda (MSC 100) ise komite, otonom gemiler için başlattığı düzenleyici kapsam belirleme çalışmalarının ilkini tamamlamıştır. 2020'de tamamlamayı planladığı kapsam belirleme çalışmaları dâhilinde görüşülmesi gereken IMO enstrümanları arasında emniyet, vardiya standartları, arama kurtarma, güvenlik, trafik kuralları, yükleme ve gemi dengesi gibi düzenlemeler bulunmaktadır. Komite bu oturumda aynı zamanda, otonom gemilerin testleri ve denemeleri için kılavuz oluşturulması için bir çalışma grubu da başlatmıştır.

Sonuç olarak, otonom ve insansız gemi konsepti günümüzde denizcilik endüstrisinin belki de en sıcak araştırma konusu durumundadır. Uluslararası kurum ve kuruluşlar bu yeni alanda rekabet avantajını elde edebilmek amacıyla girişimlerini ve faaliyetlerini yoğun bir şekilde sürdürmektedirler. Otonom gemi teknolojisi ile ilgili hızlı bir ilerlemenin kaydedildiği günümüzde Türkiye'nin de aktif olarak girişimlerde ve faaliyetlerde bulunması gerekmektedir. Türkiye'de de yukarıda örneklendirilen uluslararası faaliyetlere benzer girişimleri hayata geçirmenin ileride sahip olacağımız pasta payı açısından son derece önemlidir. Devlet kurumları, özel kuruluşlar ve üniversitelerden oluşan bir araştırma grubu oluşturmak ve INAS gibi uluslararası birliklere üye olarak aktif rol almak, Türkiye'nin otonom gemi konsepti için teknoloji üreten ülkeler arasına girmesi ve önemli bir konum elde etmesi açısından katkı sağlayacaktır. JEMS yönetimi olarak özellikle otonom gemi ve uygulamaları ile yapay zekâ uygulamaları üzerine hazırlanmış olan çalışmalara dergimizde daha sık yer vermeyi planlıyoruz.

Editör
Prof. Dr. Selçuk NAS
Yardımcı Editör
Remzi FIŞKIN

Original Research (AR) *Çiçek / JEMS, 2019; 7(2): 101-115*

Received: 07 December 2018 *Accepted: 05 February 2019* *DOI ID: 10.5505/jems.2019.72623*

Journal of ETA Maritime Science

JEMS JOURNAL

Corresponding Author: Kadir ÇİÇEK

Knowledge-Based Expert System on the Selection of Shipboard Wastewater Treatment Systems

Kadir ÇİÇEK

İstanbul Technical University, Maritime Faculty, Turkey
cicekk@itu.edu.tr; ORCID ID: https://orcid.org/0000-0002-9732-3361

Abstract

During the last 20 years, regulatory enforcements regarding with the protection of marine environment have been significantly increased. Especially, starting from 1 January 2010 a new regulation, consisting of waste water treatment plants in ships and new effluent limits, took effect. The new limits comprise a stricter review of prior limits. The strict reduction in the effluent limits for the treated wastewater discharged from ships intimates International Maritime Organization (IMO)'s intention to provide more severe control on wastewater discharges and to demand on installation wastewater treatment system that meet international requirements. Furthermore, the new limits constitute a further challenge for the manufacturing companies specified in design and manufacturing of waste water treatment systems. To way out from these points, this study focuses on development a knowledge-based expert system for selection of appropriate shipboard wastewater treatment system. Within this scope, the study proposes a hybrid approach combining AHP and TOPSIS under fuzzy environment. The three most commonly preferred shipboard wastewater treatment system types are examined and evaluated in terms of various design, operation and environment criteria.

Keywords: *Shipboard Wastewater Treatment System, AHP, TOPSIS, Fuzzy Logic, Knowledge-Based Expert System.*

Gemi Üzeri Pis Su Arıtma Sistemi Seçimine Yönelik Bilgi Tabanlı Uzman Sistemi

Öz

Son 20 yıl içerisinde, deniz çevresinin korunması ile ilgili yasal düzenlemeler önemli derecede artış göstermiştir. Özellikle, 1 Ocak 2010 yılında gemilerdeki pis su arıtma sistemlerinin atık su limitlerini düzenleyen yeni bir kural yürürlüğe girmiştir. Gemilerden tahliye edilen arıtılmış sular içerisindeki atık limitlerinin önemli derecede azalması ile beraber Uluslararası Denizcilik Örgütü (IMO) dikkatini atık su tahliyesini çok daha sıkı bir şekilde denetlemeye ve gemilere donatılan pis su arıtma sistemlerinin uluslararası gereksinimleri karşılamasına çevirmiştir. Dahası, yeni atık limitleri ile beraber üretici firmalar pis su arıtma sistemlerinin tasarımı ve üretimi ile ilgili pek çok ileri düzey zorluklar ile karşı karşıya kalmışlardır. İlgili gelişmeler çerçevesinde, bu çalışma ile gemiler için en uygun pis su arıtma ünitesinin seçimi üzerine bilgi tabanlı bir uzman sistemi geliştirilmesi üzerinde yoğunlaşılmıştır. Bu doğrultuda, bu çalışma AHP ve TOPSIS yöntemlerini bulanık tabanlı olarak birleştirerek karma bir yaklaşım önerisinde bulunmaktadır. Gemiler üzerinde yaygın olarak kullanılan 3 pis su arıtma sistemi belirlenerek, çeşitli tasarım, operasyon ve çevresel kriterlere göre değerlendirilmiştir.

Anahtar Kelimeler: *Gemi Pis Su Arıtma Sistemi, AHP, TOPSIS, Bulanık Mantık, Bilgi Tabanlı Uzman Sistemi.*

To cite this article: Çiçek, K. (2019). Knowledge-Based Expert System on the Selection of Shipboard Wastewater Treatment Systems. *Journal of ETA Maritime Science*, 7(2), 101-115.
To link to this article: https://dx.doi.org/10.5505/jems.2019.72623

1. Motivation on Study

Over the last forty years, the international concerns have been tremendously increased about the possible threats to the marine environment stem from the shipping industry. The adoption of the International Convention for the Prevention of Marine Pollution from Ships (MARPOL) can be accepted as a milestone on the prevention of marine environment caused by ship-based pollutants. The first version of MARPOL was accepted in 1973. Over the years, it has been significantly revised and it still forms the basis for the future on prevention of marine environment. Nowadays, the International Maritime Organization (IMO) works toward the concept of environmentally sound ships for the 21st Century through adopting new and stricter regulations. In the document published by North Atlantic Treaty Organization (NATO) in 2010 [1], the concept behind the environmentally sound ship is defined as; "a ship that could operate in any water body worldwide without causing significant adverse environmental impacts while complying with all applicable environmental regulations". Under the light of this definition, minimization of waste generation and appropriate treatment or disposal method for the wastes generated on board can be considered as crucial environmental issues in today's shipping industry. Nowadays, considerable research and development activities have been made to develop on-board capabilities for treating or disposing of ship-based solid and liquid wastes. Additionally, tremendous research efforts have been made to provide satisfactory solutions for treating blackwater and greywater generated on board ships.

The strict reduction in the effluent limits on treated ship wastewater intimates IMO's intention to provide stricter control on wastewater discharges and to demand on more comprehensive selection and installation progress of shipboard wastewater systems on part of the engineers and the ship-owners. To overcome the challenges in the strict restrictions of wastewater discharge, manufacturers concentrate on new researches in the design and manufacturing stages of wastewater treatment technologies. These technological improvement researches generate numerous type shipboard wastewater treatment systems (SWWTS); however, a various number of limitations on board ship, such as confined space available to install, operation and maintenance cost, limited man power, limited repair and maintenance time, and harsh environmental conditions rarify the selection of appropriate wastewater technologies for responsible stakeholders in shipping industry.

In order to support the decision-making process of actors in the shipping industry, it is necessary to use the advantages of decision-making techniques in the literature; however, there are only limited number of studies have been proposed in the literature to provide solution on SWWTS selection. At this insight, this study proposes a knowledge-based expert system integrated into a fuzzy environment to handle the vagueness and subjectivity in the selection problem. A knowledge-based expert system consists of a combination of the Fuzzy Analytic Hierarchy Process (F-AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS) methods. F-AHP is used to determine weights of the criteria, and F-TOPSIS is used to systemic evaluation of alternatives on multiple criteria.

Within this direction, the rest of the paper is organized as follows; literature review on the studies related to the scope of this study is comprehensively executed in section 2. The introduction of the proposed methodology is followed out in section 3. An application of the methodology is given in section 4. In the final section, the results and the proceeds of the proposed knowledge-based expert system are examined.

2. Literature Review

In the literature, it is possible to find a large number of studies realized by different methods to process selection, design, and operation of the wastewater treatment systems for the land-based application and the need for such studies is increasingly growing. For instance, Balmer & Mattson [2] proposed a study to analyse the wastewater treatment plant operation cost. Additionally, in 2001, Sarkis and Weinrach [3] used the advantages of Data Envelopment Analysis (DEA) method to evaluate alternative wastewater treatment technologies. Operational cost savings and capital cost savings were considered as input factors, transuranic waste and low-level waste were considered as output factors in the study. Besides, Tsagarakis et al. [4] proposed a study aiming to help engineers to evaluate wastewater projects. A cost-effectiveness criterion was introduced to evaluate alternative wastewater treatment systems in the study. As an important example of application Multi- Criteria Decision Making (MCDM) techniques in wastewater treatment system selection, Büyüközkan et al. [5] introduced an integrated MCDM model in a fuzzy environment to evaluate wastewater treatment investment from the aspects of economic effectiveness, technical feasibility, and environmental regulation. Also, Sato et al. [6] made an evaluation on sewage treatment systems respect to the total annual cost. Additionally, Anagnostopoulos et al. [7] used one of the important MCDM techniques, Analytic Hierarchy Process, combined with fuzzy logic to select wastewater facilities at the prefecture level. In 2007, Zeng et al. [8] proposed a systematic approach structured on the integration of Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA) for wastewater treatment alternatives selection. Also, Alsina et al. [9] developed a model on the decision- making process related to the multi-criteria evaluation of Wastewater Treatment Plant (WWTP) control strategies. De Foe et al. [10] described a simple multi-criteria approach for the selection of the best chemical for the treatment of urban wastewater. Alsina et al. [11] presented a study to integrate the environmental assessment and life cycle assessment for the correct assessment of wastewater treatment plants. Bottero et al. [12] compared the analytic hierarchy process and the analytic network process for the assessment of wastewater treatment systems. Karimi et al [13] adopted analytical hierarchy process and fuzzy analytical hierarchy process methods for the selection of most suitable wastewater treatment process. Kalbar et al. [14] analysed the four most commonly used wastewater treatment technologies for the treatment of municipal wastewater in India with the help of TOPSIS methodology. Ilangkumaran et al. [15] proposed a hybrid Multi-Criteria Decision Making (MCDM) methodology for the selection of wastewater treatment (WWT) technology for treating wastewater. Upadhyay [16] applied Analytical Hierarchy Process to compare sewage treatment plants in India.

On the other hand, there are only a few studies in maritime side related to the topics of process selection, design, and operation of waste-water treatment systems. One of these studies is introduced by Demboski et al. [17] in 1997. In the study, the authors made an evaluation of US-Navy shipboard sewage and grey water systems. Additionally, in 2003, Eley & Morehouse [18] focused on the evaluation of new technology for shipboard wastewater treatment. Also, the guidelines published by the International Council of Marine Industry Association regarding the introduction of the alternative wastewater treatment systems [19] can be given another example document.

Respect to the literature review, the following findings can be explained:

i) There is a big gap in the literature related to the shipboard wastewater treatment system selection problem.
ii) MCDM techniques are commonly used in Wastewater Treatment System (WWTS) selection problems.
iii) Lack of information, uncertainty, and ambiguity in the selection problems mostly solved with the adoption of fuzzy logic.

Under the lights of these findings, this study focuses on the development of a knowledge-based expert system on SWWTS selection. The proposed knowledge-based expert system is explained in following section.

3. Proposed Methodology

MCDM methods provide notable solutions in a vast amount of problems in almost all industrial fields with their advantageous features [20]. Specifically, AHP method was defined as one of the most outstanding MCDM in the literature proposed by Thomas Saaty in 1980 [21]. In compare to other MCDM methods, AHP method has been successfully applied in many practical decision-making problems [22]. In addition to AHP Method, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is another most popular MCDM method developed by Hwang and Yoon in 1981 [23] which is based on choosing the best alternative. To eliminate the uncertainty, ambiguity and lack of information shortcomings in the selection problem using the classical AHP and TOPSIS methods with its ordinary (numerical) comparison grades do not seem possible. At that point adoption of fuzzy logic into the classical MCDM methods helps researchers to minimize the aforementioned shortcomings in the selection problems. In this direction, the study proposes a hybrid methodology with the combination of AHP and TOPSIS methods under fuzzy environment to constitute a knowledge-based expert system on SWWTS selection problem. Theoretical descriptions of the methods are described in the following subsections.

3.1. Fuzzy AHP (F-AHP)

In the literature, it is possible to find various extended version of AHP method under a fuzzy environment that propose systematic approaches. This study concentrates on a F-AHP approach introduced by Chang in 1992 [24]. Chang's extent analysis method on F-AHP uses triangular fuzzy numbers for pairwise comparison scale and depends on the degree of possibilities of each criterion.

In the proposed knowledge-based expert system, a Triangular Fuzzy Number (TFN), which can be represented as M = (l, m, u), where $l \leq m \leq u$, is used. The parameters (l) and (u) represent the lower and upper value of fuzzy number M respectively and parameter (m) represents the modal value. Triangular type membership function of M fuzzy number can be described as in Eq. (1) [25].

$$\mu_M(x) = \begin{cases} 0, & x < l \\ \dfrac{x-l}{m-l}, & l \leq x \leq m \\ \dfrac{u-x}{u-m}, & m \leq x \leq u \\ 0, & x > u \end{cases} \quad (1)$$

The membership functions of the linguistic values of the weights of criteria are shown in Figure 1, and the triangular fuzzy numbers related to these variables are presented in Table 1.

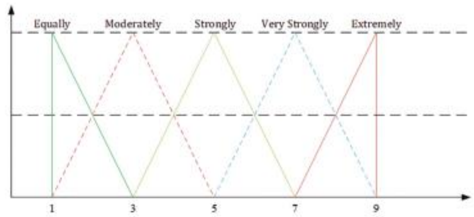


Figure 1. *Linguistic Values of the Weights of Criteria*

$$M_{g_i}^1, M_{g_i}^2, \cdots, M_{g_i}^m \quad i=1,2, \ldots, n \tag{3}$$

Chang's extent analysis [24] follows the steps described below respectively [26, 27, 28]:

Step 1: The fuzzy synthetic extent value with respect to the i_{th} object is defined as

Table 1. *Linguistic Values and TFNs to Evaluate the Weights of Criteria*

Linguistic variables	Triangular fuzzy numbers	Triangular reciprocal fuzzy numbers
Just equal (JE)	(1, 1, 1)	(1, 1, 1)
Equal importance (EI)	(1, 1, 3)	(1/3, 1, 1)
Weak importance (WI)	(1, 3, 5)	(1/5, 1/3, 1)
Strong importance (SI)	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strong importance (VSI)	(5, 7, 9)	(1/9, 1/7, 1/5)
Extremely preferred (EP)	(7, 9, 9)	(1/9, 1/9, 1/7)

By using linguistic variables and related TFNs in Table 1, the fuzzy judgement matrix $\tilde{A}(\tilde{a}_{ij})$, obtained via pairwise comparisons, can be expressed as follows:

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \begin{matrix}\tilde{a}_{121}\\ \tilde{a}_{122}\\ \vdots \\ \tilde{a}_{12P_{12}}\end{matrix} & \cdots & \begin{matrix}\tilde{a}_{1n1}\\ \tilde{a}_{1n2}\\ \vdots \\ \tilde{a}_{1nP_{1n}}\end{matrix} \\ \begin{matrix}\tilde{a}_{211}\\ \tilde{a}_{212}\\ \vdots \\ \tilde{a}_{21P_{21}}\end{matrix} & (1,1,1) & \cdots & \begin{matrix}\tilde{a}_{2n1}\\ \tilde{a}_{2n2}\\ \vdots \\ \tilde{a}_{2nP_{2n}}\end{matrix} \\ \vdots & \vdots & \ddots & \vdots \\ \begin{matrix}\tilde{a}_{n11}\\ \tilde{a}_{n12}\\ \vdots \\ \tilde{a}_{n1P_{n1}}\end{matrix} & \begin{matrix}\tilde{a}_{n21}\\ \tilde{a}_{n22}\\ \vdots \\ \tilde{a}_{n2P_{n2}}\end{matrix} & \cdots & (1,1,1) \end{bmatrix} \tag{2}$$

Let $X = \{x_1, x_2, \cdots, x_n\}$ be an object set and $G = \{g_1, g_2, \cdots, g_n\}$ is a goal set. According to Chang's fuzzy extent analysis, each object, x_i, is taken and extent analysis is performed for each goal, g_i. Therefore, m extent analysis for each object can be obtained, given as:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \tag{4}$$

$\sum_{j=1}^{m} M_{g_i}^j$ is calculated by fuzzy addition operation of m extent analysis values for a particular matrix as given below:

$$\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{i=1}^{m} l_i, \sum_{i=1}^{m} m_i, \sum_{i=1}^{m} u_i\right) \tag{5}$$

and to obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1}$, the Eq. (6) and Eq. (7) are implemented respectively:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{6}$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{7}$$

Step 2: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as:

$$V(M_2 \geq M_1) = \sup_{y \geq x}[\min(\mu_{M_1}(x), \mu_{M_2}(y),)] \quad (8)$$

and Eq. (8) can be defined as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \quad (9)$$

$$\mu_{M_2}(d) = \begin{cases} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \quad (10)$$

where, as seen in Figure 2, *d* represents the ordinate of the highest intersection point *D* between μ_{M1} and μ_{M2}. We need to calculate the values of $V(M_1 \geq M_2)$ and $V(M_1 \geq M_2)$ to make a comparison of M_1 and M_2.

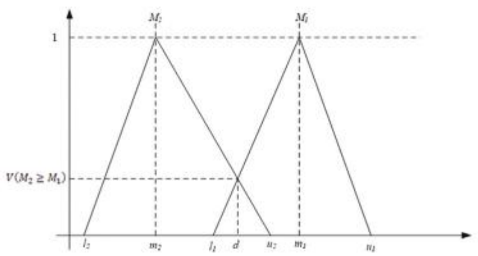


__Figure 2.__ The Intersection Between M_1 and M_2

Step 3: The possibility degree of a convex fuzzy number to be greater than k convex fuzzy numbers M_i *(i = 1,2,3, ..., k)* can be defined by

$$\begin{aligned} &V(M \geq M_1, M_2, \cdots, M_k) \\ &= V[(M \geq M_1)\ and\ (M \geq M_2)\ and \ldots and\ (M \geq M_k)] \quad (11) \\ &= \min V(M \geq M_i) \end{aligned}$$

Assuming that $d'(A_i) = \min V(S_i \geq S_k)$ for *k = 1,2, ... n; k ≠ i* Then, the weight vector is given by as:

$$W' = (d'(A_1), d'(A_2), \cdots, d'(A_k))^T \quad (12)$$

where A_i (1,2,⋯,n) has n elements.

Step 4: With normalization, the normalized weight vectors are given as:

$$W = (d(A_1), d(A_2), \cdots, d(A_k))^T \quad (13)$$

where W is a non-fuzzy number.

3.2. Fuzzy TOPSIS (F-TOPSIS)

TOPSIS is a MCDM method which was developed by Hwang and Yoon [23] in 1981. It provides to select the best alternative based on the ranking the alternatives under multiple criteria. In the study, to handle the ambiguities, uncertainties, and vagueness in the selection problem, TOPSIS method with fuzzy logic is used. It is possible to find many applications of F-TOPSIS in the literature. The extended version of TOPSIS with fuzzy logic proposed by Chen [29] is preferred to use in the study. The corresponding steps of this method are described as follows;

Step 1: The weights of the criteria (*w; j = 1, 2, ... , number of criteria*) and performance ratings of alternatives under each criterion (x_{ij}*; i = 1, 2, ... , m, number of alternatives, j = 1, 2, ... , number of criteria*) are accepted as inputs and placed in matrix form. The performance ratings, $\boldsymbol{X_{ij}}$, of alternatives are assigned by the expert with the help of linguistic variables presented in Table 2.

__Table 2.__ Linguistic Variables for Ratings

Linguistic variable	Triangular fuzzy number
Very Low	(1, 1, 3)
Low	(1, 3, 5)
Medium	(3, 5, 7)
High	(5, 7, 9)
Very High	(7, 9, 9)

With the assignments of the expert for each alternative under each criterion, the decision matrix is constructed as follows:

	C_1	C_2	⋯	C_j	⋯	C_n
A_1	$\widetilde{x_{11}}$	$\widetilde{x_{12}}$	⋯	$\widetilde{x_{1j}}$	⋯	$\widetilde{x_{1n}}$
A_2	$\widetilde{x_{21}}$	$\widetilde{x_{22}}$	⋯	$\widetilde{x_{2j}}$	⋯	$\widetilde{x_{2n}}$
⋮	⋮	⋮	⋮	⋮	⋮	⋮
A_m	$\widetilde{x_{m1}}$	$\widetilde{x_{m2}}$	⋯	$\widetilde{x_{mj}}$	⋯	$\widetilde{x_{mn}}$

Step 2: Following with the construction of the decision matrix, the normalization of the decision matrix is performed using Eq. (14) and Eq. (15):

$$\tilde{v}_{ij} = \left(\frac{a_{ij}}{c_i^*}, \frac{b_{ij}}{c_i^*}, \frac{c_{ij}}{c_i^*}\right), \quad i \in Benefit \tag{14}$$

$$\tilde{v}_{ij} = \left(\frac{a_i^-}{c_{ij}}, \frac{a_i^-}{b_{ij}}, \frac{a_i^-}{a_{ij}}\right), \quad i \in Cost \tag{15}$$

and c_i^* and a_i^- is calculated using Eq. (16) and Eq. (17);

$$c_i^* = \max_j c_{ij}, \quad if \;\; i \in Benefit \tag{16}$$

$$a_i^- = \min_j a_{ij}, \quad if \; i \in Cost \tag{17}$$

Step 3: The weighted normalized decision matrix is found by multiplying the weights of selection criteria with normalized decision matrix elements.

$$\tilde{V} = [\tilde{v}_{ij}]_{m\times n} \quad i = 1, 2, \cdots, m \; j = 1, 2, \cdots, n \tag{18}$$

where

$$\tilde{v}_{ij} = \widetilde{x_{ij}} \times w_i \tag{19}$$

Step 4: Fuzzy Positive Ideal Solution (FPIS) and the Fuzzy Negative Ideal Solution (FNIS) for each criterion are taken $\tilde{v}_i^+ = (1,1,1)$ ve $\tilde{v}_i^- = (0,0,0)$ respectively.

$$A^+ = \{\tilde{v}_1^+, \cdots, \tilde{v}_j^+, \cdots, \tilde{v}_m^+\} \tag{20}$$

$$A^- = \{\tilde{v}_1^-, \cdots, \tilde{v}_j^-, \cdots, \tilde{v}_m^-\} \tag{21}$$

Step 5: Then, the distance of each alternative from (A^+) and (A^-) are calculated as:

$$D_j^+ = \sum_{i=1}^{m} d\left(\tilde{v}_{ij}, \tilde{v}_i^+\right), \quad j = 1,2,\cdots,n \tag{22}$$

$$D_j^- = \sum_{i=1}^{m} d\left(\tilde{v}_{ij}, \tilde{v}_i^-\right), \quad j = 1,2,\cdots,n \tag{23}$$

According to the vertex method, the distance between the TFNs is calculated with the help of Eq. (24).

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \tag{24}$$

Step 6: As a final step, closeness coefficient (CC_j) is calculated to rank all possible alternatives.

$$CC_j = \frac{D_j^-}{D_j^+ + D_j^-} \quad, j = 1,2,\cdots,n \tag{25}$$

The alternative with the maximum CC_j can be selected as a most preferred option.

4. An Application: Shipboard Wastewater Treatment System Selection

The knowledge-based expert system on SWWTS selection consists of three basic stages: (1) determination the criteria and appropriate SWWTS alternatives, (2) calculation the weights of the criteria with F-AHP, (3) evaluation of alternatives with F-TOPSIS. The framework of the proposed system is presented in Figure 3. The selection criteria, alternative SWWTSs and numerical outcomes of the application are presented in the subsections respectively.

4.1. Definition of Selection Criteria

The Selection Criteria (SC) are determined with the help of literature review and industrial feedbacks. With the lack of the SWWTS selection studies in the literature, the studies such as; Buyukozkan et al. [6], Zeng et al. [8], Bottero et al. [12], Karimi et al. [13], Kalbar et al. [14], Ilangkumaran [15] and Upadhyay [16] were comprehensively analysed to figure out the general intensity on the identification the selection criteria and determination the weight of each one. Additionally, to adopt ship specific constraints into determination of the SC, the industrial feedbacks such as international standard [30], IMO circular [31], technical reports [32, 33] and news releases [34] and the manufacturers' publications [35, 36] were reviewed. Within this direction, SC of the SWWTS problem was determined as operability & maintainability (SC_1), space requirement (SC_2), energy consumption (SC_3), capital cost (SC_4), operation and maintenance cost (SC_5), and environmental compatibility (SC_6).

The SC_1 criterion considerably affects the useful life of the system. Hence it is essential to take into consideration in the

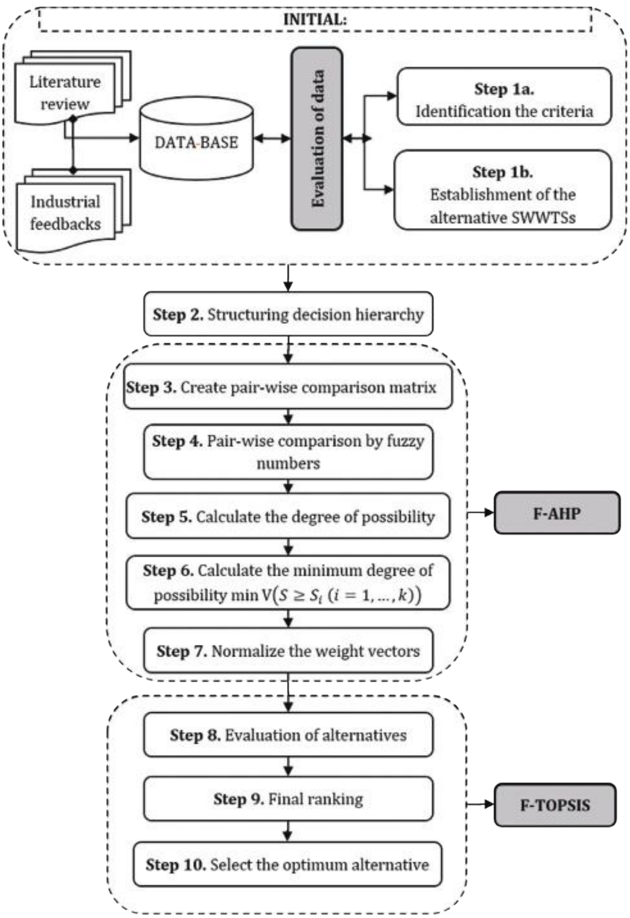


Figure 3. *Knowledge-Based Expert System on SWWTS Selection*

selection process. The SC_2 criterion focuses on the volume and weight of the system. With the limited engine room space on board ship, the volume and weight of the SWWTS turn into an important criterion on the selection process. The international enforcement related to the energy efficiency on board ships, the energy consumptions of the systems becomes quite an essential issue nowadays. For this reason, SC_3 criterion is accepted as another essential selection criterion in the study. The capital cost of the system has always a priority and substantially influences the selection of the system. At this insight, the SC_4 criterion is used in the selection of the system. In addition to capital cost, operation and maintenance cost plays a significant role in the determination of the most suitable system. To provide the system in reliable condition, it is necessary to endure the operation and maintenance cost throughout the useful life of the system. Hence SC_5 criterion is considered as an important selection criterion. Another important criterion in the selection of SWWTS is environmental compatibility. This criterion focuses on ensuring environmental regulations, meeting tough effluent discharge requirements, treating both black and grey water, no dangerous chemical additives and no microorganism to maintain for SWWTS.

The selection of optimum SWWTS which mostly fulfil the expectations is conducted under the aforementioned selection criteria. The alternatives SWWTSs, which are mostly preferred types on board ships, are presented in the following subsection.

4.3. Alternative SWWTSs

The proposed SWWTS selection procedure is demonstrated with three most commonly used alternatives on board ship which are biological, chemical and membrane wastewater treatment system. The general treatment principles of selected alternative SWWTSs are briefly explained in the following paragraphs.

Biological SWWTS (A_1) uses bacteria to facilitate the process of breaking down of solid constituents. The system consists of three compartments namely; (i) aeration compartment, (ii) settling compartment, and (iii) chemical treatment compartment. In the aeration compartment, an oxygen-rich atmosphere is generated to disintegrate the sewage waste. The disintegrated waste is then transferred to the settling compartment to settle down the solid constituents with the effect of gravity. The separated liquid from solid constituents is passed to the chemical treatment compartment. In this compartment, the liquid water is treated with chemicals to kill any surviving bacteria. After treatment, the treated water is discharged into the sea and the sludge of the wastewater is stored in a tank.

Chemical SWWTS (A_2) consists of a big storage tank which collects, treats and stores the wastewater on board ship. The collected wastewater in the storage tank is treated by chemicals to disintegrate solid constituents in the water. Also, in the chemical SWWTS, a mechanical instrument, with the name of comminutor, is used to break down the solid particles to smaller particles. The disintegrated solid particles settle down in the tank and the liquid remains at the top. Then the liquid sewage is treated with chemicals. The treated liquid can be as a flushing purpose in the toilet and can be discharged to the sea.

In the membrane SWWTS (A_3), wastewater passes into Membrane Bioreactor (MBR) which consists of a combination of membrane and biological reactor [37, 38]. In the MBR, biological purification of the sewage water occurs with the help of activated sludge which is a mixture of a number of micro-organisms [38]. Then, the treated water is separated from the activated sludge by means of filtration. Finally, the treated water is discharged into the sea and the sludge of wastewater is transferred into the tank on board.

4.4. Numerical Outcomes

With the determination of selection criteria and SWWTS alternatives, decision hierarchy is established accordingly and it is provided in Figure 4.

Following the establishment of the decision hierarchy, the weights of the criteria to be used in the selection process are calculated with the help of F-AHP method. In this phase, the expert, from one of the leading global manufacturers of equipment for ships, with six years on board and nine years onshore experiences in the maritime industry joined the selection process of the suitable SWWTS. Then, the

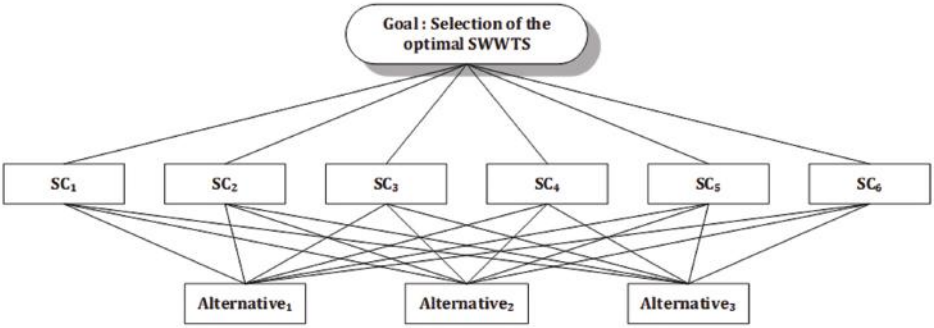


Figure 4. *The Decision Hierarchy of WWTP Selection*

Table 3. *The Sample Part of the Questionnaire*

SC_1	*EP*	*VSI*	*SI*	*WI*	*EI*	*JE*	*EI*	***WI***	*SI*	*VSI*	*EP*	**SC_2**
SC_1	*EP*	*VSI*	*SI*	*WI*	***EI***	*JE*	*EI*	*WI*	*SI*	*VSI*	*EP*	**SC_3**
SC_1	*EP*	*VSI*	*SI*	*WI*	*EI*	*JE*	*EI*	*WI*	***SI***	*VSI*	*EP*	**SC_4**
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
SC_5	*EP*	*VSI*	*SI*	*WI*	*EI*	*JE*	*EI*	***WI***	*SI*	*VSI*	*EP*	**SC_6**

Table 4. *The Pairwise Comparison Matrix for Criteria*

	SC_1	**SC_2**	**SC_3**	**SC_4**	**SC_5**	**SC_6**
SC_1	(1.00, 1.00, 1.00)	(0.20, 0.33, 1.00)	(1.00, 1.00, 3.00)	(0.14, 0.20, 0.33)	(0.20, 0.33, 1.00)	(0.11, 0.14, 0.20)
SC_2	(1.00, 3.00, 5.00)	(1.00, 1.00, 1.00)	(1.00, 3.00, 5.00)	(0.33, 1.00, 1.00)	(1.00, 3.00, 5.00)	(0.14, 0.20, 0.33)
SC_3	(0.33, 1.00, 1.00)	(0.20, 0.33, 1.00)	(1.00, 1.00, 1.00)	(0.20, 0.33, 1.00)	(0.20, 0.33, 1.00)	(0.14, 0.20, 0.33)
SC_4	(3.00, 5.00, 7.00)	(1.00, 1.00, 3.00)	(1.00, 3.00, 5.00)	(1.00, 1.00, 1.00)	(1.00, 3.00, 5.00)	(0.33, 1.00, 1.00)
SC_5	(1.00, 3.00, 5.00)	(0.20, 0.33, 1.00)	(1.00, 3.00, 5.00)	(0.20, 0.33, 1.00)	(1.00, 1.00, 1.00)	(0.20, 0.33, 1.00)
SC_6	(5.00, 7.00, 9.00)	(3.00, 5.00, 7.00)	(3.00, 5.00, 7.00)	(1.00, 1.00, 3.00)	(1.00, 3.00, 5.00)	(1.00, 1.00, 1.00)

expert is given the task to make pairwise comparisons of the selection criteria by using the scale given in Table 1 through the structured questionnaire, sample part illustrated in Table 3.

Then, linguistic pairwise comparisons of the expert are converted into fuzzy numbers and obtained pairwise comparison matrix is illustrated in Table 4.

Being able to be understood more clearly of the computation stages, the following calculation of the pairwise judgments in Table 4 are presented. The following calculations are implemented with the help of Eq. (4), Eq. (5), Eq. (6) and Eq. (7).

$$S_{SC_1} = (2.65, 3.01, 6.53) \otimes \left(\frac{1}{97.20}, \frac{1}{61.41}, \frac{1}{34.14}\right) = (0.027, 0.049, 0.191)$$

$$S_{SC_2} = (4.48, 11.20, 17.33) \otimes \left(\frac{1}{97.20}, \frac{1}{61.41}, \frac{1}{34.14}\right) = (0.046, 0.182, 0.508)$$

$$S_{SC_3} = (2.08, 3.20, 5.33) \otimes \left(\frac{1}{97.20}, \frac{1}{61.41}, \frac{1}{34.14}\right) = (0.021, 0.052, 0.156)$$

$$S_{SC_4} = (7.33, 14.00, 22.00) \otimes \left(\frac{1}{97.20}, \frac{1}{61.41}, \frac{1}{34.14}\right) = (0.075, 0.228, 0.644)$$

$$S_{SC_5} = (3.60, 8.00, 14.00) \otimes \left(\frac{1}{97.20}, \frac{1}{61.41}, \frac{1}{34.14}\right) = (0.037, 0.130, 0.410)$$

$$S_{SC_6} = (14.00, 22.00, 32.00) \otimes \left(\frac{1}{97.20}, \frac{1}{61.41}, \frac{1}{34.14}\right) = (0.144, 0.358, 0.937)$$

The obtained fuzzy synthetic extent value (S_{SCi} i = 1,2,...,6) of each selection criterion is used to calculate the possibility degrees with using Eq. (8), Eq. (9) and Eq. (10) and illustrated below.

$$V(S_{SC_1} \geq S_{SC_2}, S_{SC_3}, S_{SC_4}, S_{SC_5}, S_{SC_6}) = 0.170$$

$$V(S_{SC_2} \geq S_{SC_1}, S_{SC_3}, S_{SC_4}, S_{SC_5}, S_{SC_6}) = 0.673$$

$$V(S_{SC_3} \geq S_{SC_1}, S_{SC_2}, S_{SC_4}, S_{SC_5}, S_{SC_6}) = 0.038$$

$$V(S_{SC_4} \geq S_{SC_1}, S_{SC_2}, S_{SC_3}, S_{SC_5}, S_{SC_6}) = 0.793$$

$$V(S_{SC_5} \geq S_{SC_1} S_{SC_2}, S_{SC_3}, S_{SC_4}, S_{SC_6}) = 0.539$$

$$V(S_{SC_6} \geq S_{SC_1}, S_{SC_2}, S_{SC_3}, S_{SC_4}, S_{SC_5}) = 1$$

Following with the calculation of possibility degrees, the weight vector is calculated as using Eq. (12) and Eq. (13):

$$W' = (0.170, 0.673, 0.038, 0.793, 0.539, 1)^T$$

With normalization, the weights of the criteria are calculated as follows:

$$W = \left(d(SC_1), d(SC_2), d(SC_3), d(SC_4), d(SC_5), d(SC_6)\right)^T$$

$$W = (0.053, 0.210, 0.012, 0.247, 0.168, 0.311)^T$$

The SC_6 is obtained as a most important criterion respect to the pairwise comparisons of the expert. Additionally, SC_4 and SC_2 are determined as the second and third most important criterion respectively for the selection process of SWWTS.

After calculation of the weights, *as the first step of F-TOPSIS method*, the decision matrix based on the expert judgements by comparing alternatives with the help of linguistic variables presented in Table 2, is established. The obtained decision matrix is presented in Table 5.

Table 5. *Decision Matrix on SWWTS Selection*

Criterion / ***Alternative***	SC_1 *(0.053)*	SC_2 *(0.210)*	SC_3 *(0.012)*	SC_4 *(0.247)*	SC_5 *(0.168)*	SC_6 *(0.311)*
A_1	Medium (3, 5, 7)	Low (1, 3, 5)	Medium (3, 5, 7)	High (5, 7, 9)	Medium (3, 5, 7)	High (5, 7, 9)
A_2	High (5, 7, 9)	Medium (3, 5, 7)	Low (1, 3, 5)	Medium (3, 5, 7)	High (5, 7, 9)	Low (1, 3, 5)
A_3	Medium (3, 5, 7)	Low (1, 3, 5)	High (5, 7, 9)	Very High (7, 9, 9)	Medium (3, 5, 7)	Very High (7, 9, 9)

Following with the determination of the decision matrix, the normalized decision matrix with using the Eq. (14) for benefit criterion and Eq. (15) for cost criterion is derived. In the selection problem, SC_1, SC_2 and SC_6 are benefit criteria and SC_3, SC_4, and SC_5 are cost criteria. Then, the weighted normalized decision matrix is calculated with the help of Eq. (19) using the weights of the criteria. The weighted normalized decision matrix is shown in Table 6.

quite close to each other. For this reason, A_1 can be considered as another preferable solution.

4.5. Finding and Discussions

The study evaluates a number of key criteria on SWWTS selection. As the beginning of the analysis, the weights of the criteria are obtained as W_{SC1}=0.053, W_{SC2}=0.210, W_{SC3}=0.012, W_{SC4}=0.247, W_{SC5}=0.168, W_{SC6}=0.311. It is clearly seen

Table 6. *Weighted Decision Matrix on SWWTS Selection*

	SC1	SC2	SC3	SC4	SC5	SC6
A1	(0.018, 0.029, 0.041)	(0.030, 0.090, 0.150)	(0.002, 0.002, 0.004)	(0.082, 0.106, 0.148)	(0.072, 0.101, 0.168)	(0.173, 0.242, 0.311)
A2	(0.029, 0.041, 0.053)	(0.090, 0.150, 0.210)	(0.002, 0.004, 0.012)	(0.106, 0.148, 0.247)	(0.056, 0.072, 0.101)	(0.035, 0.104, 0.173)
A3	(0.018, 0.029, 0.041)	(0.030, 0.090, 0.150)	(0.001, 0.002, 0.002)	(0.082, 0.106, 0.106)	(0.072, 0.101, 0.168)	(0.242, 0.311, 0.311)
A^+	$\widetilde{v_1^+}$ = (1.0, 1.0, 1.0)	$\widetilde{v_2^+}$ = (1.0, 1.0, 1.0)	$\widetilde{v_3^+}$ = (1.0, 1.0, 1.0)	$\widetilde{v_4^+}$ = (1.0, 1.0, 1.0)	$\widetilde{v_5^+}$ = (1.0, 1.0, 1.0)	$\widetilde{v_6^+}$ = (1.0, 1.0, 1.0)
A^-	$\widetilde{v_1^-}$ = (0.0,0.0, 0.0)	$\widetilde{v_2^-}$ = (0.0, 0.0, 0.0)	$\widetilde{v_3^-}$ = (0.0, 0.0, 0.0)	$\widetilde{v_4^-}$ = (0.0, 0.0, 0.0)	$\widetilde{v_5^-}$ = (0.0, 0.0, 0.0)	$\widetilde{v_6^-}$ = (0.0, 0.0, 0.0)

After calculation of weighted normalized decision matrix, FPIS (A^+) and FNIS (A^-) are defined as $\widetilde{v_i^+}$ = (1.0, 1.0, 1.0) and $\widetilde{v_i^-}$ = (0.0,0.0, 0.0) for all criterion.

The distance from A^+ (F-PIS), D_i^+, and A^- (F-NIS), D_i^-, for each alternative is calculated using Eq. (22) and Eq. (23). With the calculated distances from F-PIS and F-NIS, the CC_j of each alternative is calculated with the help of Eq. (25). The results of F-TOPSIS are summarized in Table 6.

from the results that SC_6 is found as the most important criterion in the selection of SWWTSs. Also, according to the results obtained from F-AHP, SC_4 criterion is the second, SC_2 criterion is the third, SC_5 criterion is the fourth, SC_1 criterion is the fifth and SC_3 criterion is the least important criterion.

Subsequent to the calculation of the weights, F-TOPSIS method is implemented to evaluate the alternative SWWTSs. The

Table 6. *F-TOPSIS Results*

Alternatives	D_j^+	D_j^-	CC_j	Rank
A1	5,416	0,620	0,735	2
A2	5,462	0,581	0,687	3
A3	5,406	0,621	0,736	1

Based on CC_j values, A_3, *membrane SWWTS*, is found as a best alternative with CC value of 0.736. On the other hand, as seen from Table 6, CC values of A_1, *Biological SWWTS*, and A_3, *membrane SWWTS*, are

results obtained from F-TOPSIS method show that, although chemical SWWTS is better than the other alternatives with respect to the criteria of operability and maintainability, energy consumption and capital cost shortcoming in environmental compatibility made chemical SWWTS the last preference. On the other hand, membrane SWWTS is found as a best (optimum) SWWTS with its advantages in space requirement and environmental compatibility. Additionally, with technical advances, membrane SWWTS is now capable of decontaminating wastewaters in single step processes.

Avowable, the proposed knowledge-based expert system with its outstanding results helps decision makers to take the right decision on selection of the optimum ship wastewater treatment system.

5. Conclusion

SWWTS selection is an onerous process of maritime environmental management. The developing technology enables various options and selection of SWWTSs which are dependent on many factors. This study explored the potential SWWTS alternatives in the shipping industry and proposed an integrated fuzzy MCDM framework for effective SWWTS selection. The proposed methodology integrates the F-AHP and F-TOPSIS methods. The methodology provides stakeholders, ship owners, marine engineers, ship designers, and manufacturers, with a flexible manner to experience the present situation of SWWTSs and to deal with the selection of SWWTSs in the practical environmental management application. The proposed methodology enables flexibility and increases the reliability and accuracy of applications. For this reason, the proposed methodology can be extended for various environmental management applications such as the selection of alternative technologies for decreasing NO_X emission on board ship and selection of oily water treatment technologies as further studies. In addition, this study can also be extended by implementing Analytic Network Process (ANP) method whose network structure caters to all possible dependencies and interactions among selection criteria.

References

[1] North Atlantic Treaty Organization (NATO), (2010). Maritime Environmental Protection -Strategy for enhancing naval operations through ship and equipment design and management practices. (Website of NATO: www.nato.int)

[2] Balmer, P., & Mattson, B. (1994). Wastewater treatment plant operation cost. Water Science and Technology, 30 (4), 7–15.

[3] Sarkis, J., and Weinrach, J. (2001). Using data envelopment analysis to evaluate environmentally conscious waste treatment technology. Journal of Cleaner Production, 9(5), Pages 417-427.

[4] Tsagarakis, K.P., Mara, D.D., & Angelakis, A.N. (2003). Application of Cost Criteria for Selection of Municipal Wastewater Treatment Systems. Water, Air, & Soil Pollution, 142(1-4), 187-210.

[5] Büyüközkan, G., Feyzioglu, O., & Sever, F. (2005). An application of multi criteria decision making approaches for the wastewater treatment system selection problem. 35th International Conference on Computers and Industrial Engineering, 19-22 June, Istanbul, Turkey, 345-350.

[6] Sato, N., Okubo, T., Onodera, T., Agrawal, L.K., Ohashi, A., & Harada, H. (2007). Economic evaluation of sewage treatment processes in India. Journal of Environmental Management, 84(4),447-460.

[7] Anagnostopoulos, K.P, Gratziou, M., & Vavatsikos, A.P. (2007) Using the fuzzy Analytic Hierarchy Process for selecting wastewater facilities at prefecture level. European Water, 19(20), 15-24.

[8] Zeng, G., Jiang, R., Huang, G., Xu, M., & Lia, J. (2007). Optimization of wastewater treatment alternative selection by hierarchy grey relational analysis. Journal of Environmental Management, 82(2), 250-259.

[9] Alsina, X.F., Roda, I.R., Sin, G., & Gernaey, K.V. (2008). Multi-criteria evaluation of wastewater treatment plant control strategies under uncertainty. Water Research, 42(17), 4485-4497.

[10] De Foe G., De Gisi, S., & Galasso, M. (2008). Definition of a practical multi-criteria procedure for selecting the best coagulant in a chemically assisted primary sedimentation process for the treatment of urban wastewater. Desalination, 230(1-3), 229-238.

[11] Alsina X.F., Gallego, A., Feijoo, G., & Roda, I.R. (2010). Multiple-objective evaluation of wastewater treatment plant control alternatives. Journal of Environmental Management, 91(5), 1193-1201.

[12] Bottero, M., Comino, E., & Riggio, V. (2011). Application of the analytic hierarchy process and the analytic network process for the assessment of different wastewater treatment systems. Environmental Modelling & Software, 26(10), 1211-1224.

[13] Karimi, A. R., Mehrdadi, N., Hashemian, S. J., Bidhendi, G. R. N., & Moghaddam, R. T. (2011). Selection of wastewater treatment process based on the analytical hierarchy process and fuzzy analytical hierarchy process methods. International Journal of Environmental Science & Technology, 8(2), 267–280.

[14] Kalbar, P. P., Karmakar, S., & Asolekar, S. R. (2012). Selection of an appropriate wastewater treatment technology: A scenario-based multiple-attribute decision-making approach. Journal of environmental management, 113, 158-169.

[15] Ilangkumaran, M., Sasirekha, V., Anojkumar, L., Sakthivel, G., Boopathi Raja, M., T. Ruban Sundara Raj, CNS. Siddhartha, P. Nizamuddin and S. Praveen Kumar (2013). Optimization of wastewater treatment technology selection using hybrid MCDM. Management of Environmental Quality: An International Journal, 24(5), 619–641.

[16] Upadhyay, K. (2017). Application of Analytical Hierarchy Process in Evaluation of Best Sewage Treatment Plant. International Journal of Science and Research, 6(6), 259-264.

[17] Demboski D.J., Benson J.H., Rossi G.E., Leavitt N.S., Mull M.A. (1997). Evolutions in U.S. Navy Shipboard Sewage and Greywater Programs. American Society of Naval Engineers (ASNE) Environmental Symposium ’97.

[18] Eley, W.D., & Morehouse, C.H. (2003). Evaluation of new technology for shipboard wastewater treatment. Proceedings of Oceans 2003 Conference, Marine Technology Society, Columbia, Maryland, 748-753.

[19] International Council of Marine Industry Association (ICOMIA), (2007). ICOMIA guide to on-board treatment of grey-water, 2nd-Edition.

[20] Torfi F., Farahani, R.Z., & Rezapour, S. (2010). Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives. Applied Soft Computing, 10, 520-528.

[21] Saaty, T.L. (1980). The Analytic Hierarchy Process. McGraw Hill Company, New York.

[22] Saaty, T.L. (1988). Multi-criteria Decision Making: The Analytic Hierarchy Process, RWS Publications, Pittsburgh, PA.

[23] Hwang, C.L., & Yoon, K., (1981). Multiple Attributes Decision Making Methods and Applications, Springer, Berlin Heidelberg.

[24] Chang, D.Y. (1992). Extent analysis and synthetic decision. Optimization Techniques and Applications, 1, 352–355.

[25] Triantaphyllou, E. (2000) Multi-Criteria Decision Making Methods: A Comparative Study. Kluver Academic Publishers, Dordrecht.

[26] Bozbura, F. T., Beşkese, A., & Kahraman, C. (2007). Prioritization of human capital measurement indicators using fuzzy AHP. Expert Systems with Applications, 32, 1100–1112.

[27] Kahraman, C., Cebeci, U., & Ruan, D. (2004). Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey. International Journal of Production Economics, 87, 171–184.

[28] Kahraman, C., Ruan, D., & Doğan, I. (2003). Fuzzy group decision making for facility location selection. Information Sciences, 157, 135–153.

[29] Chen, C.T. (2000) Extensions of the TOPSIS for group decision making under fuzzy environment. Fuzzy Sets and Systems, 114, pp.1-9.

[30] International Standard Organization, (2004). ISO 15749-1:2004: Ships and marine technology - Drainage systems on ships and marine structures - Part 1: Sanitary drainage-system design.

[31] International Maritime Organization Publication (1994). MSC/Circ. 648, Annex Guidelines for the operation, inspection and maintenance of ship sewage systems.

[32] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/282353/mgn033.pdf

[33] Web Page: www.emsa.europa.eu/work/download/4557/2925/23.html

[34] Web Page: https://www.ship-technology.com/contractors/wastewater/techni-sa/

[35] Web Page: http://www.headhunterinc.com/product/sewage-treatment-2/?gclid=EAIaIQobChMIxJm-zqTo3wIVk0PTCh0rqg1_EAMYAyAAEgIvVfD_BwE

[36] Web Page: http://hosent.co.kr/

[37] Visvanathan, Chettiyappan & Ben Aim, Roger. (2018). Membrane Bioreactor Applications in Wastewater Treatment.

[38] Web Page: http://www.acomarine.com/products/wastewater-treatment-plants/membrane-wastewater-treatment-system/, 06.12.2018, 14:11.

This Page Intentionally Left Blank

Received: 04 January 2019 *Accepted: 07 February 2019* *DOI ID: 10.5505/jems.2019.98704*

Journal of ETA Maritime Science

JEMS JOURNAL

Corresponding Author: Emrah GÜMÜŞ

Gemi Dizel Motoruna Alternatif: sCO2 Güç Çevrimi

Emrah GÜMÜŞ

Bağımsız Araştırmacı, İstanbul, Türkiye
e_gumus@yahoo.com; ORCID ID: https://orcid.org/0000-0002-0900-2825

Öz
Süperkritik CO2 güç çevrimlerine olan ilgi son yıllarda hızla artmaktadır. Bu ilginin başlıca nedenleri bu sistemlerde yüksek çevrim verimlerinin elde edilebilmesi, karbondioksit gazının ucuz, ısıl olarak kararlı, kritik nokta civarında yoğunluk ve özgül ısısının yüksek olması gibi özellikleridir. Bu çalışmada, sCO2 tekrar sıkıştırmalı Brayton güç çevriminin termodinamik hesaplamaları gerçekleştirilmiş tasarım noktasındaki çalışma basınç ve sıcaklık değerleri, türbin gücü, kompresör güçleri, ısı değiştirici ısıl yük değerleri ve çevrim verimi hesaplanmıştır. Hesaplamalar sonucunda %44,6 çevrim verimi ve 189 gr/kWh özgül yakıt tüketimine sahip bir güç çeviriminin mümkün olduğu ve bu çevrimin dizel motorlara alternatif olabileceği değerlendirilmiştir.

Anahtar Kelimeler: *CO2, Süperkritik, Dizel, Güç Çevrimi, Brayton.*

Alternative to Ship Diesel Engine: sCO2 Power Cycle

Abstract
The interest in supercritical CO2 power cycles is increasing rapidly in recent years. The main reasons for this interest are high cycle efficiency of these systems, carbon dioxide gas being cheap, thermally stable, and having high density and specific heat capacity around the critical point. In this study, pressure and temperature values of the cycle state points, turbine power, compressor powers, heat exchanger thermal loads and cycle efficiency at the design point were calculated for the sCO2 re-compression Brayton power cycle. As a result of the calculations, a power cycle with a cycle efficiency of 44.6% and a specific fuel consumption of 189 g/kWh is seem to be feasible and this cycle can be considered as an alternative to diesel engines.

Keywords: *CO2, Supercritical, Diesel, Power Cycle, Brayton.*

To cite this article: Gümüş, E. (2019). Gemi Dizel Motoruna Alternatif: sCO2 Güç Çevrimi. *Journal of ETA Maritime Science*, 7(2), 117-126.
To link to this article: https://dx.doi.org/10.5505/jems.2019.98704

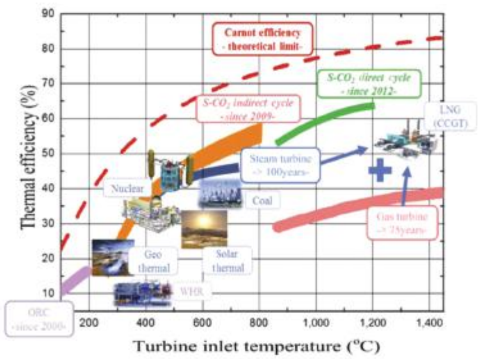
1. Giriş

Süperkritik karbondioksit (sCO_2) çevrimlerinin ara ara kesintilere uğramış uzun bir tarihçesi vardır. Kaynaklarda belirtilen ilk uygulama Sulzer kardeşler tarafından 1948 senesinde patenti alınmış yarı-yoğuşmalı CO_2 Brayton çevrimidir [1]. Bu tarihten sonra konu üzerinde araştırmalar devam etmesine rağmen dikkatleri bu çevrimlere çeken asıl çalışmalar 1960'lı yıllarda Feher tarafından yapılan süperkritik termodinamik güç çevrimlerinin incelendiği çalışmalar olmuştur [2, 3]. Feher'in "süperkritik" olarak adlandırdığı çevrimde o zamana kadar uygulananların aksine akışkan çevrim boyunca devamlı kritik basınç değerinin üzerinde çalıştırılmıştır. Yapılan termodinamik hesaplamalarda çalışma sıvısı olarak CO_2 seçilmiştir. Bu tercihin başlıca nedenleri olarak CO_2'nin (1) kritik basıncının suyun üçte biri olması böylece düşük çevrim basınçlarına izin vermesi (2) ısıl olarak kararlı olması (3) literatürde termodinamik özelikleri ile ilgili yeterli bilgi bulunması (4) toksik olmaması, ucuz ve bol olması gösterilmiştir. Süperkritik çevrimler ile yüksek ısıl verimlilik değerlerinin elde edilebileceğinin söylendiği çalışmada, bunların uzay uygulamaları için elektrik üretimi, deniz uygulamaları için şaft gücü üretimi ve sabit/portatif karasal elektrik üretimi uygulamaları için uygun olacağı sonucu paylaşılmıştır. Ayrıca, CO_2'nin çalışma sıvısı ve nükleer reaktörün ısı kaynağı olacağı durumlarda kompakt ve portatif güç üreteçlerinin tasarlanabileceği ifade edilmiştir. Bu alandaki bir diğer önemli çalışma da Angelino tarafından 1969 senesinde gerçekleştirilmiştir [4]. Angelino CO_2 ile çalışan farklı çevrim modellerini incelemiş ve bunların verimlilik değerlerini kıyaslamıştır. Yapılan çalışmada tekrar-sıkıştırmalı çevrim yüksek ısıl verim ile, ısı-geri kazanımlı çevrim basit, düşük maliyetli ve az yer kaplaması ile ön plana çıkmıştır.

1990'ların sonuna kadar sCO_2 çevrimleri ile alakalı kayda değer herhangi bir çalışma yapılmamıştır. Bu durumun temel nedenleri olarak yetersiz turbo makine bilgisi, bu çevrimlere uygun kompakt ısı değiştirici teknolojilerinin olmaması, yüksek sıcaklık ve basınç uygulamaları için yetersiz malzeme bilgisi gösterilebilir. Ancak günümüzde özellikle buhar çevrimleri ve gaz türbinleri konularında elde edilen bilgi birikimi bu alandaki gelişmelerin önünü açmıştır. 1968 yılında Feher tarafından önerilen nükleer enerji uygulaması, Çek Cumhuriyeti'nde yapılan çalışmalar ile tekrar hız kazanmıştır [5, 6]. Petr ve arkadaşları yapmış oldukları çalışmalarda ısı-geri kazanımlı ve tekrar-sıkıştırmalı çevrimler üzerine yoğunlaşmış ve bu çevrimlerin yeni nesil nükleer enerji santrallerinde kullanımını incelemiştir. Çalışma ile sCO_2 çevrimlerinin aynı şartlardaki helyum ve hava çevrimlerine göre daha verimli olduğu ve malzeme kısıtları nedeniyle türbin giriş sıcaklığının 600° C ile sınırlı olduğu sonuçları paylaşılmıştır. Amerika Birleşik Devletleri'ndeki araştırmaların canlanması ise Dostal tarafından Massachusetts Institute of Technology (MIT)'de yapılan çalışmalar ile olmuştur [7]. Dostal yaptığı çalışmada nükleer enerji santrali uygulamalarına yönelik çevrim optimizasyonu, bileşen tasarımları, ekonomik analiz, çevrim kontrol yöntemleri ve sistem yerleşim çalışmalarını da içeren detaylı bir araştırma gerçekleştirilmiştir.

Nükleer enerji uygulamalarına yönelik başlayan çok sayıda çalışma ile sCO_2 güç çevrimlerinin üstünlükleri (küçük turbomakine ve ısı değiştirici boyutları, hava ile soğutmaya uygunluk, vs.) daha belirgin hale gelmiş ve bu çevrimlerin atık ısı geri kazanımı, güneş enerjisi, jeotermal enerji, kömür santralleri ve gemi tahrik sistemleri gibi farklı alanlara da uygulanmaları üzerine yoğun çalışmalar başlatılmıştır (***Şekil 1***). Bu kapsamda başta Amerika Birleşik Devletleri olmak üzere Kore, Çin, Çek Cumhuriyeti, İspanya, Hollanda, Hindistan, Norveç, Avustralya, İtalya, İsviçre, Fransa ve Kanada gibi gelişmiş ülkelerde sCO2 güç çevrimleri üzerine devam eden çok sayıda çalışma bulunmaktadır [8].

Bu çalışmada, sCO2 tekrar sıkıştırmalı güç çevriminin jeneratör tahrikinde kullanılan YANMAR 6EY18AL 4 stroklu, 6 silindirli dizel motora[10] alternatif olup olamayacağına yönelik fizibilite çalışması gerçekleştirilecektir. Termodinamik çevrim hesapları yapılarak güç ve ısıl yük değerleri, çevrim verimi ile yakıt tüketimi değerleri hesaplanıp dizel motor ile kıyaslaması yapılacaktır. Ayrıca güç çevrimi ısıl verimine etki eden önemli parametrelerden ana kompresör giriş sıcaklığı ve basıncı, ana kompresör çıkış basıncı ve türbin giriş sıcaklığının belirlenmesine yönelik yapılan çalışmalara da yer verilecektir.

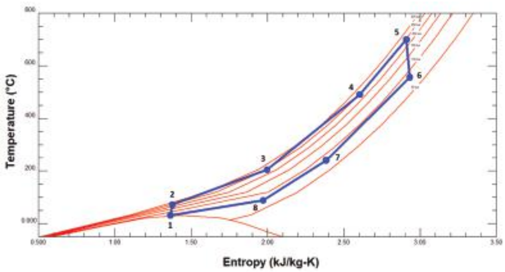


Şekil 1. Güç Çevrim Sistemlerinin Isıl Verimlilikleri ve Uygulama Alanları [9]

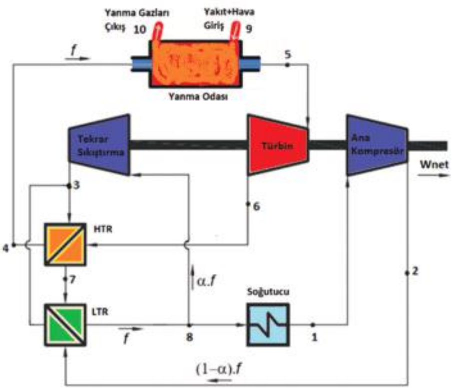
2. Tekrar Sıkıştırmalı sCO2 Güç Çevrimi Hesaplamaları

Tekrar sıkıştırmalı süperkritik CO2 Brayton çevrimi (TSSBÇ), çalışma sıvı olarak karbondioksit gazının kullanıldığı kapalı döngü bir güç çevrimidir. ***Şekil 2***'deki T-s diyagramından görüleceği üzere çevrimin çalıştığı sıcaklık ve basınç değerlerinin tamamı çalışma sıvısının kritik noktasının üzerinde olduğundan, bu çevrim süperkritik Brayton çevrimi olarak adlandırılmaktadır.

Şekil 3'de akış şeması gösterilen TSSBÇ beş ana bileşenden oluşmaktadır: türbin, kompresörler, reküperatörler, soğutucu ve yanma odası. TSSBÇ'de soğutucudan önce ikinci bir kompresör (tekrar sıkıştırma kompresörü) daha kullanılarak çevrim dışına atılan ısı miktarı azaltılıp toplam çevrim verimi arttırılmaktadır. Düşük sıcaklık reküperatoründen (LTR) geçen akış ikiye ayrılarak (durum 8) bir kısmı tekrar sıkıştırma kompresörüne gönderilmekte, kalan kısım ise soğutucudan geçirildikten (8-1) sonra ana kompresörde yüksek basınca çıkartılıp (1-2) LTR'de ısı ilave edilmektedir (2-3). Tekrar sıkıştırmaya gönderilen kısım kompresörde yüksek basınca çıkartıldıktan (8-3) sonra yüksek sıcaklık reküperatörüne (HTR) sokulmakta ve burada türbinden çıkan sıcak akışkanın ısısını alarak yanma odasına girmeden önce ön ısıtmaya maruz kalmaktadır. Yanma



Şekil 2. Tekrar Sıkıştırmalı Çevrimin T-s Diyagramı



Şekil 3. Tekrar Sıkıştırmalı Çevrim Akış Şeması

odasında sıcaklığı arttırılan akışkan (4-5) türbinde genleştirilerek (5-6) şaft gücü elde edilmektedir. Bu şaft gücü istenirse jeneratör vasıtasıyla elektrik enerjisi üretmek için istenirse de dişli kutusu vasıtasıyla pervanelere güç vermek için kullanılabilir.

TSSBÇ termodinamik analizleri sırasında aşağıdaki varsayımlar yapılmıştır:

- Çevrimdeki her bir bileşende Kararlı Durum, Kararlı Akış vardır.
- Adyabatik fakat izentropik olmayan genleşme ve sıkıştırma olmaktadır.
- Soğutucu hariç diğer bileşenlerden çevrim dışına herhangi bir ısı kaybı yoktur.
- Kinetik ve potansiyel enerjilerdeki değişimler ihmal edilebilir seviyededir.

Çevrim hesabına öncelikle her bir noktanın basınç değerinin bulunması ile başlanır. Eğer akış boyunca (i-j) basınç düşümü $\Delta P_{i-j} = P_i - P_j$ ile ifade edilirse, her bir bileşen için basınç düşümü aşağıdaki şekilde hesaplanabilir:

$$P_3 = P_2 - \Delta P_{2-3} ;\ P_4 = P_3 - \Delta P_{3-4} ;\ P_5 = P_4 - \Delta P_{4-5} ;\ P_6 = P_7 + \Delta P_{6-7} ;\ P_7 = P_8 + \Delta P_{7-8} ;\ P_8 = P_1 + \Delta P_{8-1} \quad (1)$$

Türbin ve kompresör verimleri aşağıdaki şekilde tanımlanır:

$$\eta_{mc} = \frac{h_{2s}-h_1}{h_2-h_1} \quad (2)$$

$$\eta_{rc} = \frac{h_{3s}-h_8}{h_3-h_8} \quad (3)$$

$$\eta_t = \frac{h_5-h_6}{h_5-h_{6s}} \quad (4)$$

Burada h_{2s}, P_2 ve s_1'deki entalpi değeri; h_{3s}, P_3 ve s_8'deki entalpi değeri ve h_{6s}, P_6 ve s_5'deki entalpi değeridir.

Termodinamiğin ilk kanunu kullanılarak türbin ve kompresörler için özgül güçler ile çevrime ait net özgül güç çıkışı aşağıdaki denklemler kullanılarak hesaplanır:

$$w_t = h_5 - h_6 \quad (5)$$
$$w_{mc} = (1 - \propto)(h_2 - h_1) \quad (6)$$
$$w_{rc} = (\propto)(h_2 - h_1) \quad (7)$$
$$w_{net} = w_t - w_{mc} - w_{rc} \quad (8)$$

Düşük sıcaklık reküperatöründeki enerji dengesinden akış ayrım oranı ∝ hesaplanır:

$$(1 - \propto)(h_3 - h_2) = (h_7 - h_8) \quad (9)$$

Çevrime giren özgül ısı miktarı ile çevrimden atılan özgül ısı miktarı aşağıdaki şekilde hesaplanır:

$$q_{in} = h_5 - h_4 \quad (10)$$
$$q_{out} = (1 - \propto)(h_8 - h_1) \quad (11)$$

Özgül net güç çıkışı ve özgül ısı girişi belirlendikten sonra çevrim verimi hesaplanır:

$$\eta_{cycle} = w_{net} / q_{in} \quad (12)$$

kW cinsinden net güç ihtiyacı (W_{net}) ve net özgül güç çıkışı kullanılarak CO2 akışkanın kütlesel debisi hesaplanır:

$$\dot{m}_{CO2} = W_{net} / w_{net} \quad (13)$$

Daha önce bulunan özgül güç ve ısı değerleri ile $\dot{m}_{CO2}$ kullanılarak kW cinsinden güç ve ısı değerleri aşağıdaki denklemler kullanılarak bulunur:

$$W_t = \dot{m}_{CO2}\, w_t \quad (14)$$
$$W_{mc} = \dot{m}_{CO2}\, w_{mc} \quad (15)$$
$$W_{rc} = \dot{m}_{CO2}\, w_{rc} \quad (16)$$
$$Q_{in} = \dot{m}_{CO2}\, q_{in} \quad (17)$$
$$Q_{out} = \dot{m}_{CO2}\, q_{out} \quad (18)$$
$$Q_{LTR} = \dot{m}_{CO2}\, q_{LTR} \quad (19)$$
$$Q_{HTR} = \dot{m}_{CO2}\, q_{HTR} \quad (20)$$

Etkenlik, ısı değiştiricinin sağladığı ısı transferi değerinin (Q) sağlayabileceği maksimum değere (Q_{max}) bölümü ile elde edilir ve aşağıdaki şekilde ifade edilir:

$$\varepsilon = Q / Q_{max} \quad (21)$$

Denklem (21)'deki Q ve Q_{max} değerleri aşağıdaki gibi bulunabilir:

$$Q = \dot{m}_{hot} \, (h_{hotIn} - h_{hotOut}) = \dot{m}_{cold} \, (h_{coldOut} - h_{coldIn}) \quad (22)$$

$$Q_{max} = C_{min} \, (T_{hotIn} - T_{coldIn}) \quad (23)$$

T_{hotIn} sıcak akımın ısı değiştiriciye giriş sıcaklığı, T_{coldIn} soğuk akımın ısı değiştiriciye giriş sıcaklığıdır. C_{min} minimum ısı kapasitesi oranıdır ve sıcak akım ya da soğuk akım ısı kapasitesi değerlerinden en küçük olanına eşittir ve aşağıdaki denklem kullanılarak bulunur:

$$C_{min} = Min \left[\frac{Q}{T_{hotIn} - T_{hotOut}} ; \frac{Q}{T_{coldOut} - T_{coldIn}} \right] \quad (24)$$

İhtiyaç duyulan yakıt miktarı, yanma odası verimi (η_{comb}) ve yakıt alt ısıl değeri (Qlhv) kullanılarak aşağıdaki denklem ile bulunur:

$$\dot{m}_{fuel} = Q_{in} / (\eta_{comb} \, Qlhv) \quad (25)$$

Özgül yakıt tüketimi ise yakıt tüketimi ve yapılan net iş kullanılarak aşağıdaki şekilde hesaplanır:

$$SFC = \dot{m}_{fuel} / W_{net} \quad (26)$$

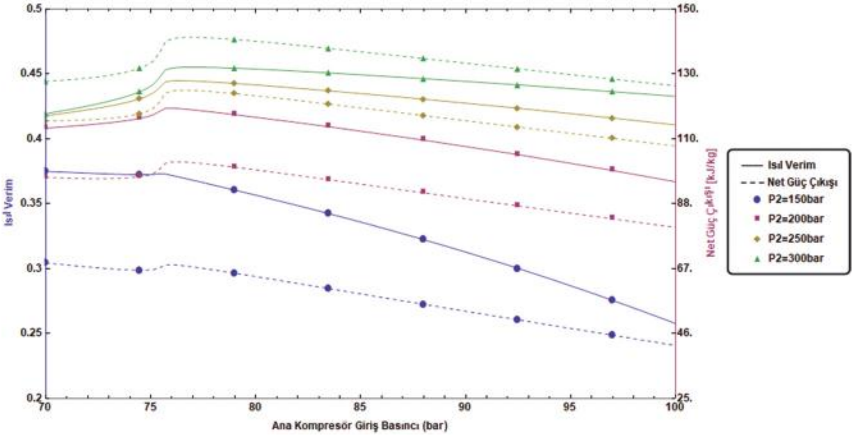
3. Bulgular ve Değerlendirmeler

TSSBÇ termodinamik hesaplamaları Mathematica programında yazılan kod ile gerçekleştirilmiş ve CO2 akışkanın termodinamik özelikleri Span ve Wagner [11] tarafından geliştirilen hal denklemlerini kullanan REFPROP programı kütüphanesinden elde edilmiştir. Yazılan kod ile Tablo 1'de paylaşılan tasarım girdileri kullanılarak tüm durum noktalarına ait sıcaklık ve basınç değerleri ile çevrim bileşenlerine ait güç veya ısıl yük bilgileri hesaplanmıştır. Aksi belirtilmedikçe tabloda verilen girdiler kullanılmış olup performans analizi boyunca sadece etkisi incelenen girdi değeri(leri) değiştirilmiştir. Ana kompresör giriş ve çıkış basınçları ile türbin giriş sıcaklığı ve ana kompresör giriş sıcaklıklarının çevrim verimi ve net güç çıkışına etkileri incelenmiştir.

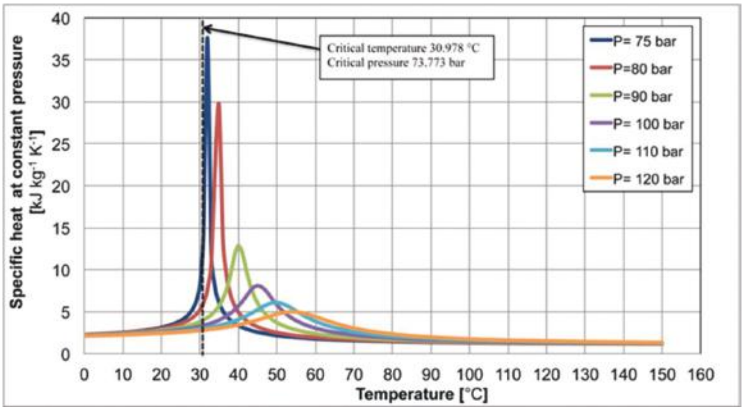
Şekil 4'de ana kompresör giriş ve çıkış basıncının çevrim verimi ve net çıkış gücüne etkisi gösterilmiştir. Bu şeklin oluşturulması sırasında giriş basıncı 70 bar ile 100 bar arasında değiştirilmiş ve bu hesaplamalar 150 bar, 200 bar, 250 bar ve 300 bar çıkış basınçlarının her biri için tekrar edilmiştir. Şekildeki düz çizgiler çevrim veriminin, kesik çizgiler net güç çıkışının farklı çıkış basınçları için değişimini ifade etmektedir. Şekil 4 incelendiğinde hem verimin hem de net güç çıkışının CO2 akışkanının kritik basıncı (73,7 bar) civarında keskin değişiklikler gösterdiği görülmektedir. Bu durumun nedeni Şekil 5'de görüleceği gibi kritik nokta civarında CO2'nin özgül ısısında görülen keskin değişikliklerdir.

Tablo 1. *Tekrar Sıkıştırmalı Çevrim Tasarım Girdileri*

Girdiler	
Net güç çıkışı, Wnet	600 kW
Ana kompresör giriş basıncı, P_1	76,3 bar
Ana kompresör çıkış basıncı, P_2	250 bar
Ana kompresör giriş sıcaklığı, T_1	32 ^{0}C
Türbin giriş sıcaklığı, T_5	700 ^{0}C
Ana kompresör verimi, η_{mc}	%85
Tekrar sıkıştırma kompresör verimi, η_{rc}	%85
Türbin verimi, η_t	%90
Yanma odası verimi, η_{comb}	%95
LTR etkenliği, ε_{LTR}	%90
HTR etkenliği, ε_{HTR}	%90
Basınç düşümleri, ΔP	2 bar
Yakıt alt ısıl değeri, Qlhv	42.700 kJ/kg



Şekil 4. Isıl Çevrim Verimi ve Net Güç Çıkışının Ana Kompresör Giriş-Çıkış Basınçlarına Göre Değişimi



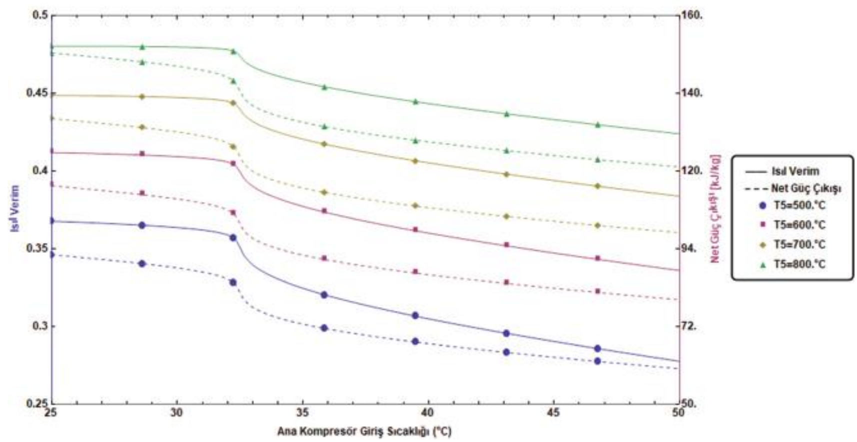
Şekil 5. CO2 Akışkanının Özgül Isısının Değişimi [12]

Şekil 4'den sabit kompresör çıkış basıncı için giriş basıncı arttıkça verim ve güç çıkışında önce bir artış ardından hafif bir düşüş olduğu gözlemlenir. Giriş basıncının arttırılması, kompresör basınç oranının azalmasına böylece kompresörler için ihtiyaç duyulan güç miktarının azalmasına neden olur. Kritik nokta civarında kompresör gücündeki düşüş (yüksek özgül ısı değişikliklerinden dolayı) türbin gücündeki düşüşe göre çok daha fazladır. Bu nedenle net güç çıkışında bir artış görülür. Bununla birlikte, giriş koşulu kritik noktadan uzaklaştıkça bu fark önemsiz hale gelir ve değişkenler neredeyse sabit bir davranış gösterir. Grafiklerden belirli bir çıkış basıncında maksimum verim veya maksimum güç çıkışına sahip olmak için optimum bir giriş basıncı değeri olduğu görülmektedir. Bu giriş basıncı değeri maksimum verim ve maksimum güç çıkışı için farklılık gösterir. Örneğin, 250 bar çıkış basıncı için maksimum çevrim verimi (44,6%) 76,3 bar'da görülürken maksimum özgül güç çıkışı (123,8 kJ / kg) 76,6 bar'da gözlenir.

Şekil 4'ten sabit bir kompresör giriş basıncı durumu için de gözlemler yapılabilir. Giriş basıncını sabit tutarken çıkış basıncını artırmak net gücü ve verimi arttırır. Çıkış basıncı arttıkça hem kompresör gücü hem de türbin gücü artar, ancak türbin gücündeki artış kompresörlere kıyasla daha fazla olduğundan çevrim verimi artar. Öte yandan, verimdeki artış döngü kritik noktadan uzaklaştıkça daha yüksek basınçlar için önemsiz hale gelir. Bu nedenle, ısıl verim başlangıçta artar ve sonrasında neredeyse sabit kalır. Bu davranış 250 bar ve 300 bar verim çizgilerinin birbirine yakınlığı ile doğrulanabilir. Kritik nokta civarındaki sabit kompresör giriş basıncı için, çıkış basıncının 150 bar'dan 200 bar'a yükseltilmesi verimlilikte büyük bir fark yaratırken, 250 bar'dan 300 bar'a yükseltmenin önemli bir etkisi yoktur. Bu nedenden ötürü nihai güç çevriminde ana kompresör çıkış basıncı olarak 250 bar seçilmiş, 250 bar çıkış basıncı için maksimum verimi veren 76,3 bar'da giriş basıncı değeri olarak belirlenmiştir. Çıkış basıncının 250 bar olarak belirlenmesindeki diğer nedenler sistemde kullanılacak borulama ekipmanlarının, ısı değiştiricilerin ve diğer devre elemanlarının tedarik edilebilirliği ve maliyetleridir. 700^{0}C sıcaklık ve 250 bar üstü basınçlar için deniz taşıtlarına ait standartları karşılayan devre elemanları bulmak hem zor hem de maliyetlidir.

Şekil 6, çevrim verimi ve net güç çıkışının ana kompresör giriş (minimum çevrim) sıcaklığı ile değişimini farklı türbin giriş (maksimum çevrim) sıcaklıkları için göstermektedir. Sabit bir türbin giriş sıcaklığında, kompresör giriş sıcaklığının artması hem ısıl verimi hem de net güç çıkışını azaltır. Ana kompresörün giriş sıcaklığı arttıkça, yeniden sıkıştırma kompresörüne giden akış miktarı artar ve ihtiyaç duyulan basınç oranı için daha fazla kompresör gücü gerekir. Bu nedenle, artan ana kompresör giriş sıcaklığı, toplam kompresör gücünü arttırır, dolayısıyla net güç çıkışını azaltır. Sabit bir türbin giriş sıcaklığı için, minimum çevrim (ana kompresör giriş) sıcaklığı arttıkça, çevrime giren ısı miktarı azalır. Bununla birlikte, net güç çıkışındaki yüzdelik azalma, ısı girişindeki yüzdelik azalmadan daha yüksek olduğundan net etki ısıl verimde bir düşüş şeklinde olur.

Şekil 6'dan ana kompresör giriş sıcaklığının sabit, türbin giriş sıcaklığının değişken olduğu durumu incelemek de mümkündür. Türbin giriş sıcaklığının arttırılması, türbin tarafından üretilen gücü arttırmakta, dolayısıyla çevrimin net güç çıkışını arttırarak çevrim verimini arttırmaktadır. Ana kompresör giriş sıcaklığı ile çevrim verimi değişimi incelendiğinde giriş sıcaklığının CO2 kritik noktasına (30,98^{0}C) yakın olmasının



Şekil 6. *Isıl Çevrim Verimi ve Net Güç Çıkışının Ana Kompresör Giriş Sıcaklığı ve Türbin Giriş Sıcaklığına Göre Değişimi*

çevrim verimini arttırdığı gözlenmektedir. Bu nedenle tasarımı düşünülen güç çevrimi için ana kompresör giriş sıcaklığı 32^{0}C olarak belirlenmiştir. Gene grafiklerden türbin giriş sıcaklığı ne kadar yüksek olursa çevrim veriminin de bir o kadar yüksek olduğu görülmektedir. Ancak bu noktada malzeme teknolojisinin sınırları, tasarımı yapılacak türbin için kullanılacak malzemelerin tedarik ve maliyetleri gibi konular göz önünde bulundurulmalıdır. Ayrıca yüksek sıcaklıklarda çalışma diğer çevrim elemanlarının maliyetlerinin artmasına da neden olacaktır. Tüm bu durumlar göz önünde bulundurulduğunda düşünülen güç çevrimi için maksimum sıcaklık değeri 700^{0}C olarak belirlenmiştir.

Performans hesaplamaları sonucunda belirlenen ana kompresör giriş ve çıkış basınçları, ana kompresör giriş sıcaklığı, türbin giriş sıcaklığı ve hesaplamalar sırasında ihtiyaç duyulan diğer girdiler Tablo 1'de paylaşılmış ve bu değerler kullanılarak güç üretim çevrimine ait enerji hesaplamaları gerçekleştirilmiştir. Çevrim noktalarına ait sıcaklık, basınç, entalpi ve entropi değerleri Tablo 2'de paylaşılmıştır. Tablo 3'de çevrim bileşenlerine ait güç ve ısıl yük değerleri, Tablo 4'de çevrimdeki CO2 kütlesel debileri ve Tablo 5'de düşünülen güç üretim sistemine ait yakıt tüketim değerleri gösterilmektedir. Hesaplamalarda %44,6 verime sahip 600 kW güç üretebilen bir tekrar sıkıştırmalı süperkritik CO2 Brayton çevriminin tasarlanabileceği ve bu güç sisteminin 189 gr/kWh'lik bir özgül yakıt tüketimi değerine sahip olabileceği görülmektedir. Bu yakıt tüketimi değeri mukayesesi yapılan YANMAR 6EY18AL dizel motorunun tam yükteki tüketim değeri olan 204 gr/kWh [10] ile karşılaştırıldığında %7,4'lik bir kazanca işaret etmektedir.

Tablo 2. *Çevrim Noktalarına Ait Değerler*

Durum Noktası	P (bar)	T (^{0}C)	h (kJ/kg)	s (kJ/kg.K)
1	76,3	32	311,4	1,364
2	250	72	341,7	1,377
3	248	205	591,4	1,998
4	246	491	958,1	2,603
5	244	700	1221,8	2,910
6	82,3	556	1052,2	2,933
7	80,3	241	685,5	2,383
8	78,3	89	506,1	1,971

Tablo 3. *Enerji Denge Tablosu*

Enerji	kW	%
Çevrime giren ısı miktarı	1346	100
Türbin tarafından üretilen güç	822	
Ana kompresör tarafından harcanan güç	106	
Tekrar sıkıştırma kompresörü tarafından harcanan güç	116	
HTR ısıl yükü	1778	
LTR ısıl yükü	870	
Soğutucu ısıl yükü	678	
Net enerji çıkışı	600	44,6

Tablo 4. *CO2 Kütlesel Debiler*

Debi	kg/s	%
Toplam kütlesel debi	4,85	100
Ana kompresöre giden akış miktarı	3,48	
Tekrar sıkıştırmaya giden akış miktarı	1,37	28,2

Tablo 5. *Yakıt Tüketim Verileri*

Debi	
Yakıt tüketimi	31,5 gr/s
Özgül yakıt tüketimi	189 gr/kWh

4. Sonuç

Bu çalışmada, sCO2 tekrar sıkıştırmalı güç çevriminin termodinamik hesaplamaları gerçekleştirilmiş tasarım noktasındaki çalışma basınç ve sıcaklık değerleri, türbin gücü, kompresör güçleri, ısı değiştirici ısıl yük değerleri ve çevrim verimi hesaplanmıştır. Hesaplamalar sonucunda %44,6 çevrim veriminin elde edilebileceği, tasarlanacak sCO2 güç çevriminin 189 gr/kWh ile mukayesesi yapılan YANMAR 6EY18AL dizel motordan %7,4 daha az özgül yakıt tüketim değerine sahip olduğu tespit edilmiştir. Bu çalışmada elde edilen bulgular sonucunda sCO2 güç çevriminin dizel motorlara alternatif olabileceği değerlendirilmektedir.

Kaynaklar

[1] Sulzer (1948), Verfahren zur Erzeugung von Arbeit aus Warme. Swiss Patent: 269 599.

[2] E. Feher (1962), Supercritical Thermodynamic Cycles for External and Internal Combustion Engines, Astropower, Inc. Engineering Report, 1962.

[3] E. Feher (1968), The Supercritical Thermodynamic Power Cycle, Energy Conversion., no. VOL.8, pp. 85-90.

[4] G. Angelino (1969), Real Gas Effects in CarbonDioxide, ASME, 69-GT-102, no. 102.

[5] V. Petr ve M. Kolovratnik (1997), A Study on Application of a Closed Cycle CO2 Gas Turbine in Power Engineering (in Czech), Czech Technical University in Prague, Department of Fluid Dynamics and Power Engineering, Division of Power Engineering, Departmental report Z-523/97.

[6] V. Petr, M. Kolovratnik ve V. Hanzal (1999), On the Use Of CO2 Gas Turbine in Power Engineering (in Czech), Czech Technical University in Prague, Department of Fluid Dynamics and Power Engineering, Division of Power Engineering, Departmental report Z-530/99.

[7] V. Dostal (2004), A Supercritical Carbon Dioxide Cycle for Next Generation Nuclear Reactors, Doktora Tezi, Massachusetts Institute of Technology, Massachusetts, USA.

[8] R. Dennis (2014), NETL, Erişim Tarihi: 17 Nisan 2016, http://www.netl.doe.gov/File%20Library/Events/2014/sco2workshop/1-3---US-DOE-SCO2-Project-summaries.pdf.

[9] Y. Ahn, S. J. Bae, M. Kim, S. K. Cho, S. Baik, J. I. Lee ve J. E. Cha, (2015), Review Of Supercritical CO2 Power Cycle Technology And Current Status Of Research And Development, Nuclear Engineering and Technology, no. 47, pp. 647-661.

[10] A. Parlak ve G. Kökkülünk (2016), Bir Gemi Dizel Motorunun Performans Ölçümü ve Değerlendirilmesi, JEMS, cilt 4(2), pp. 165-173.

[11] R. Span ve W. Wagner (1996), A new Equation of State for Carbon Dioxide Covering the Fluid Region from Triple-Point Temperature to 1100 K at Pressures up to 800 MPa, J. Phys. Chem. Ref. Data, cilt Vol.25, no. No.6, pp. 1509-1596.

[12] Unilab Srl. (2017). What happens to fluid properties near the critical point?. Erişim Tarihi: 3 Ocak 2019, http://www.unilab.eu/articles/fluid-properties-near-critical-point/.

Received: 05 December 2018 *Accepted: 07 February 2019* *DOI ID: 10.5505/jems.2019.08860*

Journal of ETA Maritime Science

JEMS JOURNAL

Corresponding Author: Şakir BAL

Numerical Investigation of Propeller Skew Effect on Cavitation

Şakir BAL

Istanbul Technical University, Naval Architecture & Ocean Eng. Faculty, Turkey
sbal@itu.edu.tr; ORCID ID: https://orcid.org/0000-0001-8688-8482

Abstract

This paper addresses the skew effects (a significant geometric property) of marine propellers on cavitation phenomenon numerically. DTMB 4381, 4382, 4383 and 4384 model propellers with different skew values have been chosen to investigate the cavity patterns on the blades under open water conditions. A lifting surface method has been applied for both non-cavitating and cavitating propellers. Numerical results (non-dimensional thrust and torque coefficients, efficiency values and cavity patterns on the blades) have been validated with experimental results. It has been found that the present numerical method is accurate and reliable for predicting the hydrodynamic performance of both non-cavitating and cavitating propeller under open water conditions. It has also been found that under certain conditions the skewed blades of the propeller can cause lesser cavity patterns and improve the propeller performance.

Keywords: *Cavitation, Propeller, Skew, Lifting Surface Method.*

Pervane Çalıklığının Kavitasyon Üzerine Etkisinin Sayısal İncelenmesi

Öz

Bu çalışmada, gemi pervanelerinin önemli bir geometrik özelliği olan çalıklığın kavitasyon oluşumu üzerindeki etkileri sayısal olarak incelenmiştir. Bunun için farklı çalıklık değerlerine sahip DTMB 4381, 4382, 4383 ve 4384 model pervaneleri seçilmiş ve açık su şartları altında kanatlar üzerindeki kavitasyon oluşumları hesaplanmıştır. Bir kaldırıcı yüzey yöntemi hem kavitasyon yapan hem de yapmayan pervaneler için uygulanmıştır. Öncelikle, elde edilen sayısal sonuçlar (boyutsuz itme ve tork, verim değerleri ve kanatlar üzerindeki kavitasyon oluşumları) deneysel sonuçlarla doğrulanmıştır. Böylece mevcut yöntemin açık su şartları altında hem kavitasyonlu durumda hem de kavitasyonsuz durumda güvenilirliği ve doğruluğu gösterilmiştir. Çalışma neticesinde belirli şartlar altında artan çalıklık miktarının pervane kanatları üzerinde daha az kavitasyon oluşumuna sebep olacağı ve pervane hidrodinamik performansını iyileştirebileceği bulunmuştur.

Anahtar Kelimeler: *Kavitasyon, Pervane, Çalıklık, Kaldırıcı Yüzey Yöntemi.*

To cite this article: Bal, Ş. (2019). Numerical Investigation of Propeller Skew Effect on Cavitation. *Journal of ETA Maritime Science*, 7(2), 127-136.
To link to this article: https://dx.doi.org/10.5505/jems.2019.08860

1. Introduction

It is difficult to avoid the cavitation on propeller blades of modern surface marine vehicles due to the increase of loading. It is well-known that the cavitation can cause vibration, noise, erosion on blades and reduction in efficiency which will eventually deteriorate the functionality and performance of marine vehicles. The skewed propeller can delay or reduce the cavitation amount under certain conditions and improve propeller performance.

In the past, the effects of skew have been studied by various researchers. In [1], the cavitation on a highly skewed propeller DTMB 4384 has been investigated by a RANS (Reynolds-Averaged Navier-Stokes) simulation. The computational results have been validated with experiments. It has been reported that an increase in skew angle is effective to avoid cavitation. In another study [2], unsteady RANS and Bubble Dynamics equations were coupled to predict the cavitation on propeller blades. It was noted that the proper increase in blade skew angle may reduce the cavitation pattern and improve the hydrodynamic performance of the propeller. In [3], the cavitating flows around a highly skewed model propeller under both uniform and non-uniform wake conditions were modelled by applying a mass transfer cavitation technique. This technique used the Rayleigh-Plesset equation and k-ω turbulence model. It was noted in the study that sheet cavitation as well as tip vortex cavitation that was observed in tests, were regenerated around the flows of highly skewed cavitating propellers. In addition, the relationship between the skew angle and propeller trailing (vortex) wake was numerically investigated in [4] and several model propellers with different skew angles were used in this study. Numerical simulations were based on RANS method. It was found that the contraction of trailing (vortex) wake can be limited with an increase in skew angle and loading conditions. The interaction between cavitating patterns and propeller skew was also examined numerically by using different skewed propellers in [5]. RANS solver was again applied to predict cavitation pattern and pressure values in propeller wake. It was found that under certain operating conditions for high blade loading, sheet cavitation becomes weak with an increase in propeller skew angle. A boundary element method was, on the other hand, applied to examine the skew effect on propeller performance in [6]. But no cavitation analyses were included in the calculations. Effects of advance ratio on the wake evolutions for skewed propeller were investigated numerically in [7]. The skew effect was also analyzed numerically for just one advance ratio in [8]. However, in these studies, RANS simulations applied generally and these studies have not considered a systematic investigation of skew on cavitation.

On the other hand, a lifting surface method for the analysis of unsteady flows around marine propellers working under non-uniform inflow conditions was introduced in [9]. An extended version of this method later was developed for cavitating propellers in [10]. A search algorithm for cavity detachment for back and mid-chord cavitation was also added in the method [11]. Lifting surface method was later improved by taking into account of viscous effects and of a technique for cavitation inception [12]. The viscous effects were assumed to be dominant near the leading edge of the blade sections. Later, a numerical method based on [12] was developed in [13]. This method improved significantly the cavitation simulation on the blades of the propeller [13]. A simpler method based on a lifting line model to compute the propeller hydrodynamic performance was also later introduced in [14]. This method was applied to investigate the podded propulsors, too in [15]. A lifting surface method similar to the present study was used to analyze both non-cavitating and cavitating optimized propellers under open water conditions [16, 17]. It is well-known that a lifting surface method is cost-effective, simpler and faster than RANS solutions.

In the present study, a very fast and reliable lifting surface method similar to the one used in [16] has been selected to analyze the cavitating and non-cavitating propeller with skew. The influence of skew angle on cavitation and hydrodynamic performance of propeller has been discussed under open water conditions.

2. Numerical Method

A lifting surface method is applied to calculate the hydrodynamic performance of cavitating propellers as similar to the one given in [17]. The method is summarized here for the completeness of the paper. The lifting surface method models unsteady cavitating flow around a marine propeller. The method assumes an incompressible and irrotational flow around a cavitating marine propeller. There are finite numbers of vortices and sources distributed on the blade camber surface and its wake surface. The strengths of source distribution are calculated by using the thickness distribution in the chord-wise direction. They are independent of time as also given in [18]. Moreover, the unknown strengths of bound vortices on the blade surface can be determined by applying the kinematic boundary condition.

The dynamic boundary condition that is based on Bernoulli's equation requires that the pressure must be equal to the vapor pressure of water on the cavity surface. A searching mechanism is applied her for the unknown cavity extent and length in the direction of each spanwise strip. The cavity thickness, area, and volume can then be found by using the integration technique of the cavity source distribution along each strip. A time domain approach is also used to solve the problem. Each time increment represents an angular position of rotation of the propeller. A uniform frictional drag coefficient is also assumed to calculate the viscous forces.

When the propeller is working under steady flow conditions, the loading on all blades is the same. Hence, the total force and torque of the propeller are calculated by multiplying each blade force and torque by the number of blades. Hub effects can also be included in the calculations by the method of images. The other details of the lifting surface method applied here for propeller analysis are given in [16] and [19].

3. Validation and Numerical Results

For a systematic analysis of skew effect, DTMB 4381, 4382, 4383 and 4384 model propellers have been selected since the cavitation and open water results were presented for these series of skewed propellers in [20, 21]. The main dimensions of the propellers 4381, 4382, 4383 and 4384, which are taken from [20, 22] are given in Table 1, Table 2, Table 3 and Table 4, respectively. Each propeller has a diameter of 30.48 cm, five blades, BAR (Blade Area Ratio) = A_E/A_0 = 0.725, and NACA a=0.8 camber lines with 66 modified thickness sections. They have similar chord and thickness distributions. The series has maximum projected skew angles 0^0 (4381), 36^0 (4382), 72^0 (4383) and 108^0 (4383) at the propeller tip. The geometry and panels used in this study are also shown in Figure 1.

First, the lifting surface method is applied to non-cavitating DTMB 4381, 4382, 4383 and 4384 propellers for validation. The number of vortex elements is (N=20) in the chord-wise direction and (M=30) in the radius direction of blades. These number of panels have been found to get converged results after some numerical tests. The frictional drag coefficient was assumed to be C_f=0.0035 in the calculations. The thrust and torque coefficients (K_T and KQ) and efficiency value [η=(J/2Π)*(K_T/K_Q)] of four propellers (4381, 4382, 4383 and 4384) versus advance coefficients (J) computed from the lifting surface analysis are validated with experiments given in [21] as shown in Figures 2, 3, 4 and 5, respectively. The agreement between the results of analysis and experiments is satisfactorily good. For all propellers, the maximum efficiency about J=1 has the same value except DTMB 4382 model propeller which has a slightly lower efficiency under open water and non-cavitating conditions.

Table 1. *Main Dimensions of DTMB 4381 Propeller*

r/R	c/D	P/D	Skew (^{0})	Rk/D	t_{max}/D	f_{max}/c
0.2	0.174	1.332	0	0	0.0434	0.0351
0.25	0.202	1.338	0	0	0.0396	0.0369
0.3	0.229	1.345	0	0	0.0358	0.0368
0.4	0.275	1.358	0	0	0.0294	0.0348
0.5	0.312	1.336	0	0	0.0240	0.0307
0.6	0.337	1.280	0	0	0.0191	0.0245
0.7	0.347	1.210	0	0	0.0146	0.0191
0.8	0.334	1.137	0	0	0.0105	0.0148
0.9	0.280	1.066	0	0	0.0067	0.0123
0.95	0.210	1.031	0	0	0.0048	0.0128
1.0	0.000	0.995	0	0	0.0029	0.0000

Table 2. *Main Dimensions of DTMB 4382 Propeller*

r/R	c/D	P/D	Skew (^{0})	Rk/D	t_{max}/D	f_{max}/c
0.2	0.174	1.455	0.000	0.0000	0.0434	0.0430
0.25	0.202	1.444	2.328	0.0093	0.0396	0.0395
0.3	0.229	1.433	4.655	0.0185	0.0358	0.0370
0.4	0.275	1.412	9.363	0.0367	0.0294	0.0344
0.5	0.312	1.361	13.948	0.0527	0.0240	0.0305
0.6	0.337	1.285	18.378	0.0656	0.0191	0.0247
0.7	0.347	1.200	22.747	0.0758	0.0146	0.0199
0.8	0.334	1.112	27.145	0.0838	0.0105	0.0161
0.9	0.280	1.027	31.575	0.0901	0.0067	0.0134
0.95	0.210	0.985	33.788	0.0924	0.0048	0.0140
1.0	0.000	0.942	36.000	0.0942	0.0029	0.0000

Table 3. *Main Dimensions of DTMB 4383 Propeller*

r/R	c/D	P/D	Skew (^{0})	Rk/D	t_{max}/D	f_{max}/c
0.2	0.174	1.566	0.000	0	0.0434	0.0402
0.25	0.202	1.539	4.647	0	0.0396	0.0408
0.3	0.229	1.512	9.293	0	0.0358	0.0407
0.4	0.275	1.459	18.816	0	0.0294	0.0385
0.5	0.312	1.386	27.991	0	0.0240	0.0342
0.6	0.337	1.296	36.770	0	0.0191	0.0281
0.7	0.347	1.198	45.453	0	0.0146	0.0230
0.8	0.334	1.096	54.245	0	0.0105	0.0189
0.9	0.280	0.996	63.102	0	0.0067	0.0159
0.95	0.210	0.945	67.531	0	0.0048	0.0168
1.0	0.000	0.895	72.000	0	0.0029	0.0000

Table 4. *Main Dimensions of DTMB 4384 Propeller*

r/R	c/D	P/D	Skew (^{0})	Rk/D	t_{max}/D	f_{max}/c
0.2	0.174	1.675	0.000	0.0000	0.0434	0.0545
0.25	0.202	1.629	6.961	0.0315	0.0396	0.0506
0.3	0.229	1.584	13.921	0.0612	0.0358	0.0479
0.4	0.275	1.496	28.426	0.1181	0.0294	0.0453
0.5	0.312	1.406	42.152	0.1646	0.0240	0.0401
0.6	0.337	1.305	55.199	0.2001	0.0191	0.0334
0.7	0.347	1.199	68.098	0.2269	0.0146	0.0278
0.8	0.334	1.086	81.283	0.2453	0.0105	0.0232
0.9	0.280	0.973	94.624	0.2557	0.0067	0.0193
0.95	0.210	0.916	101.300	0.2578	0.0048	0.0201
1.0	0.000	0.859	108.000	0.2578	0.0029	0.0000

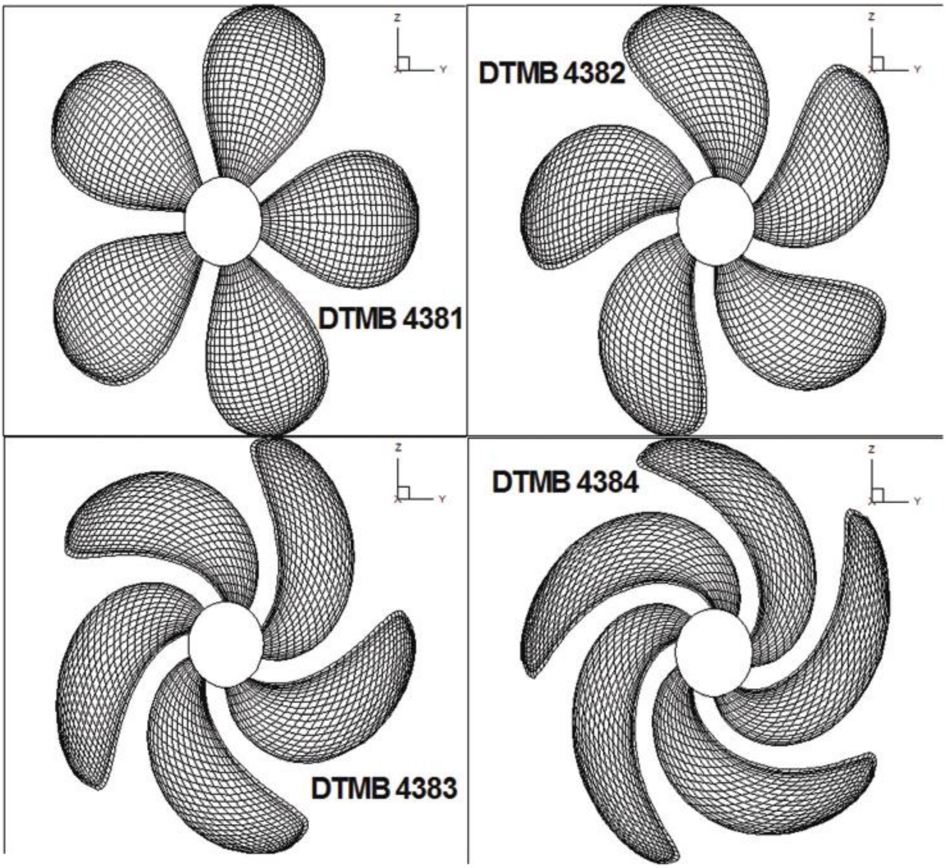


Figure 1. *Front Views and Panels of Four Propellers*

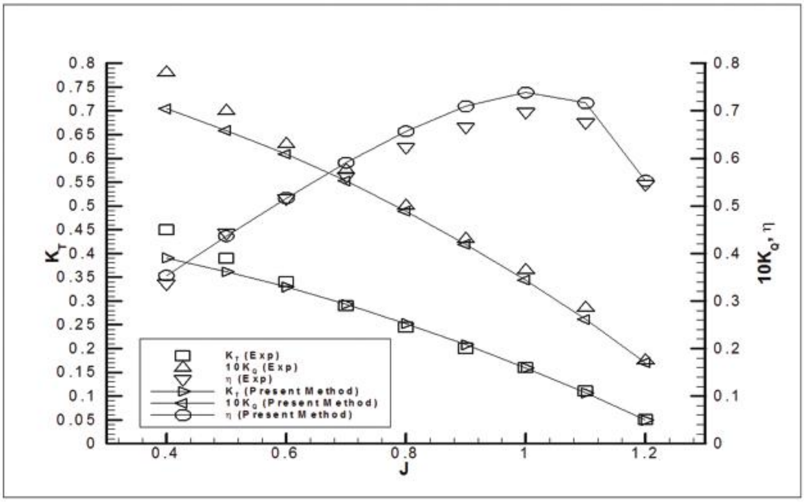


Figure 2. *Comparison of Open Water Results with Experiment (DTMB 4381)*

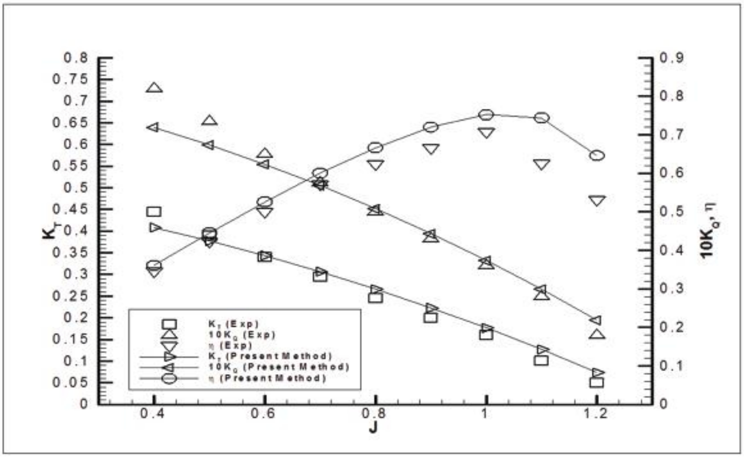


Figure 3. *Comparison of Open Water Results with Experiment (DTMB 4382)*

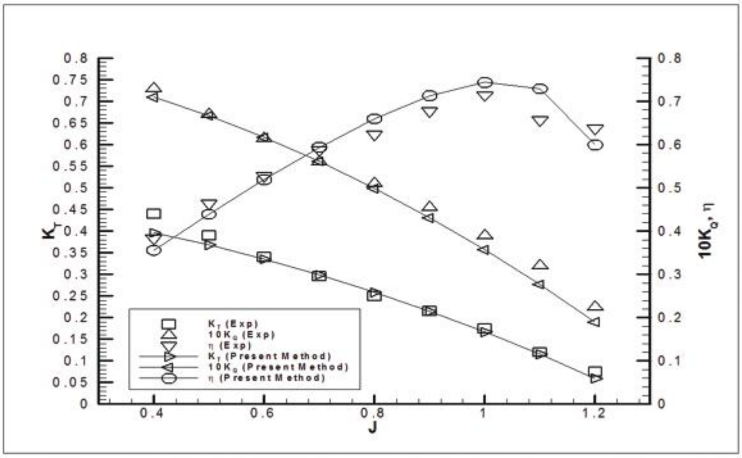


Figure 4. *Comparison of Open Water Results with Experiment (DTMB 4383)*

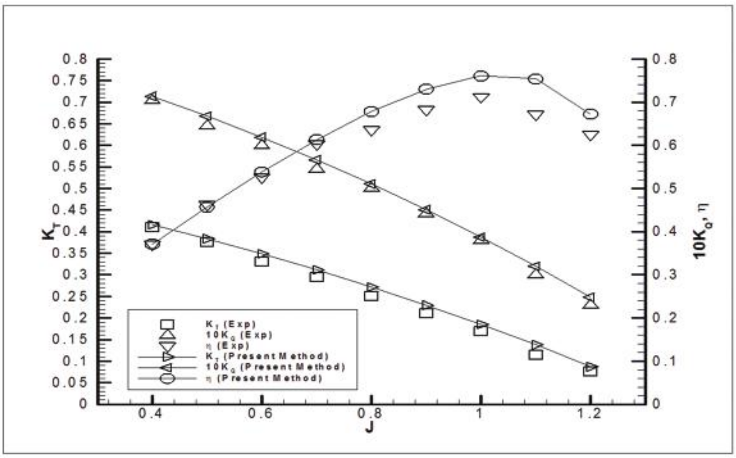


Figure 5. *Comparison of Open Water Results with Experiment (DTMB 4384)*

Later, the lifting surface method is applied to cavitating DTMB 4381 and 4382 propellers for validation. The advance coefficient is selected as J=0.7 and the cavitation number σ=1.715 for validation under cavitating conditions [21]. The non-dimensional cavitation number is defined as:

$$\sigma = \frac{p - p_V}{\frac{1}{2}\rho(nD)^2}$$

Here, p is the static pressure on the shaft axis of propeller, pV is the vaporize pressure of water. ρ is the density of water, n is the revolution speed (revolution per second) and D is the diameter of propellers. The computed cavity patterns (J=0.7 and σ=1.715) by present method are compared with experiments [21] for DTMB 4381 and 4382 propellers as shown in Figures 6 and 7, respectively. Note that the agreement between two is satisfactory for practical engineering applications except near very local region around mid-radius of DTMB 4381 model propeller. The tip vortex cavity has also been captured very well for both propellers.

Then, the lifting surface method is applied to all cavitating propellers (DTMB 4381, 4382, 4383 and 4384). The advance coefficient is first assumed to be J=0.8 (low loading on propeller) and the cavitation number is σ=1.9. The computed cavity patterns by present method are shown for four propellers as shown in Figure 8. Note that the cavity area is almost the same for all propellers. It does not change with a skew angle. The only difference for this case (low loading condition on propeller) is that tip vortex cavity is starting to develop with an increase in skew angle. The advance coefficient is later assumed to be J=0.4 (higher loading on propeller) and the cavitation number is σ=2.9. The computed cavity patterns by present method are shown for four propellers as shown in Figure 9. Note that the cavity area is now reducing for propellers which have increasing skew angles. Note also for this case (higher loading condition on propeller) that tip vortex cavity is starting to develop much larger than the previous case, with an increase in skew angle.

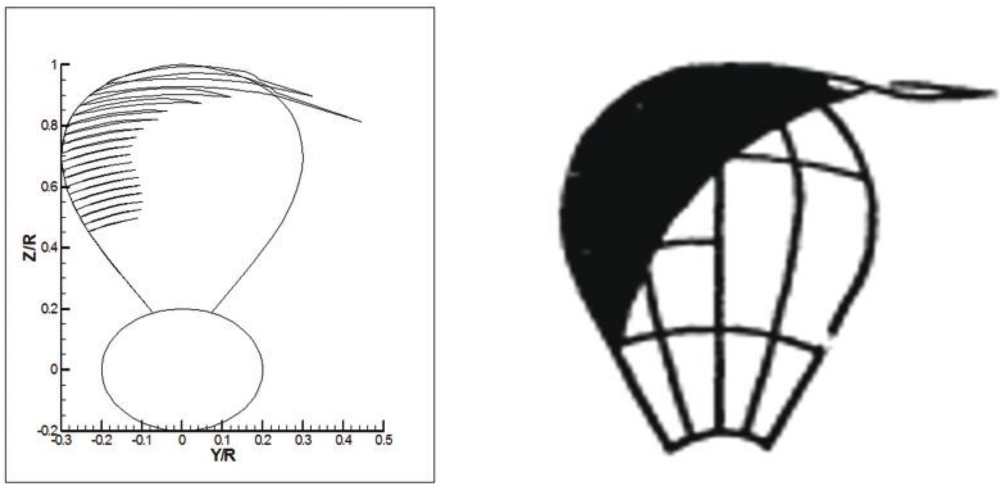


Figure 6. *Comparison of Cavity Pattern with Experiments, J=0.7, σ=1.715 (DTMB 4381) (Left: Present Method, Right: Experiment taken from [21])*

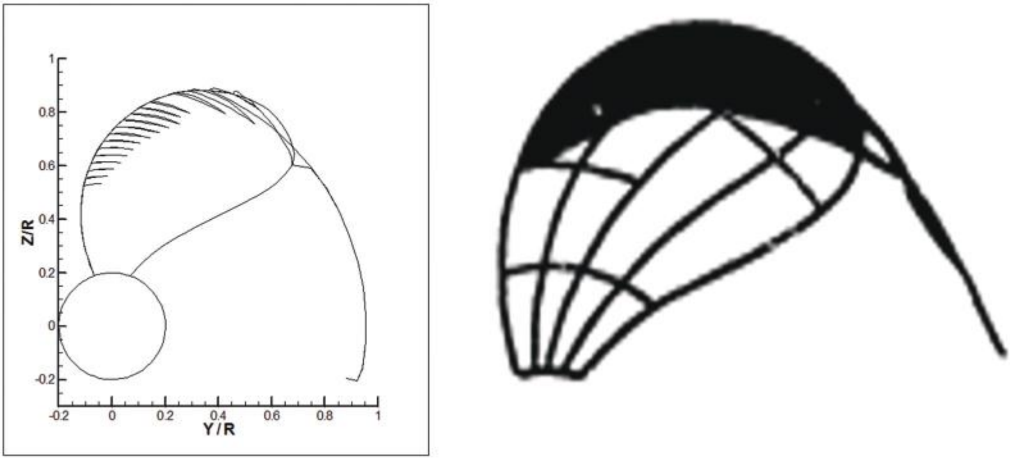


Figure 7. *Comparison of Cavity Pattern with Experiments, J=0.7, σ=1.715 (DTMB 4382) (Left: Present Method, Right: Experiment taken from [21])*

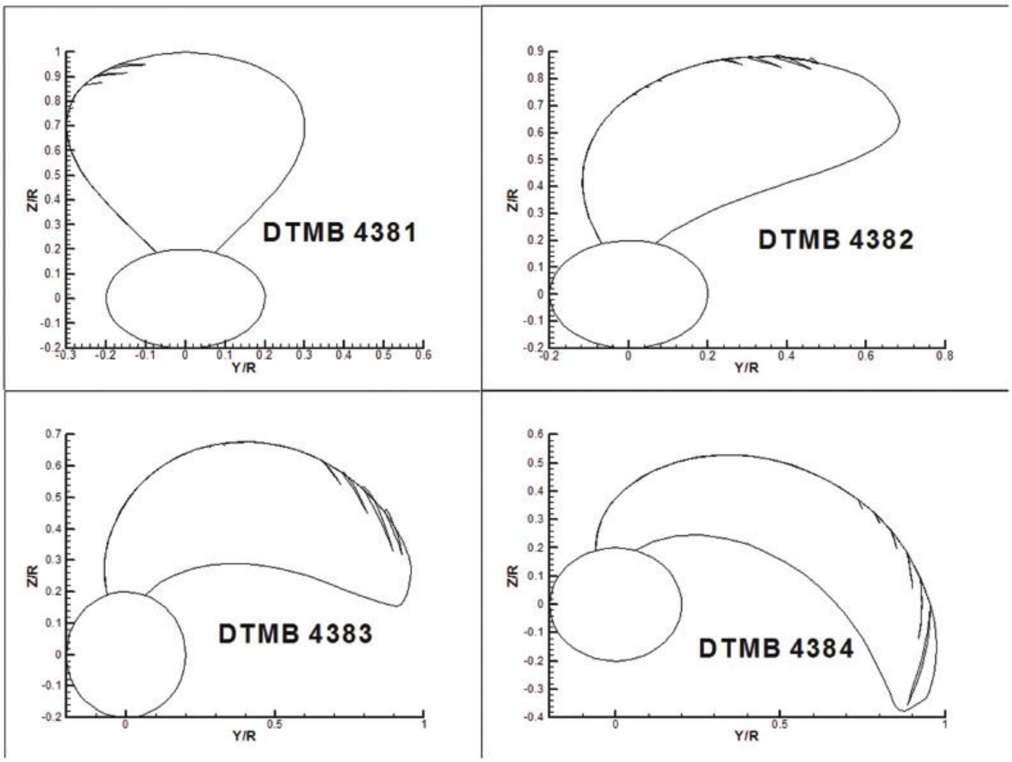


Figure 8. *Cavity Patterns of Four Propellers for J=0.8, σ=1.9*

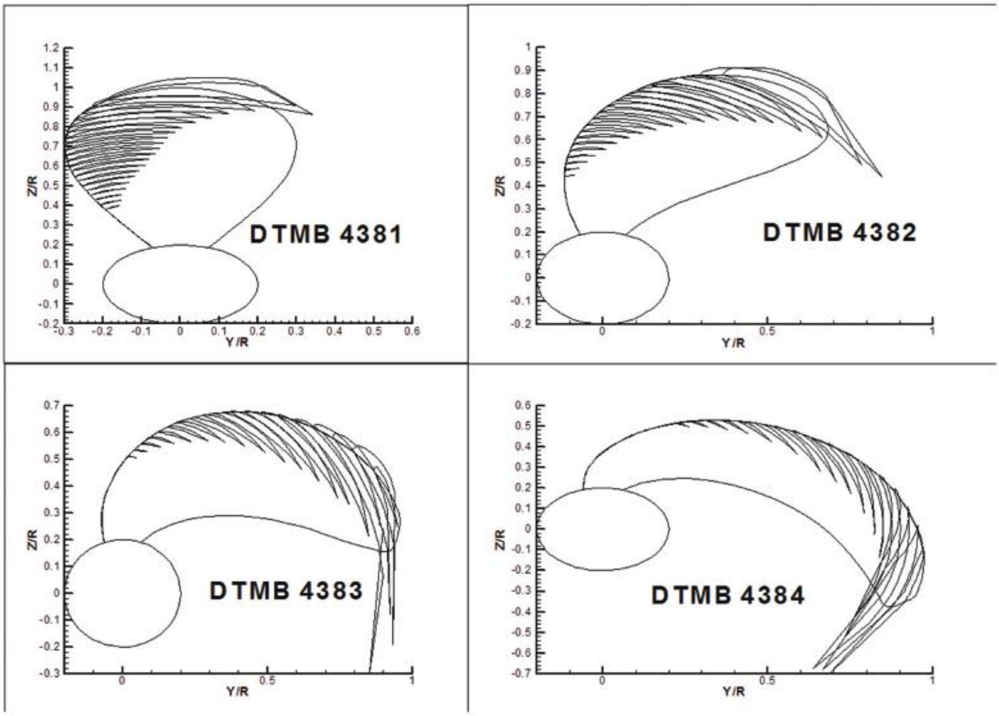


Figure 9. Cavity Patterns of Four Propellers for J=0.4, σ=2.9

4. Conclusions

In this study, the skew influence on cavitation has been investigated by a lifting surface method. It has been found that all four propellers (DTMB 4381, 4382, 4383 and 4384) under non-cavitating conditions have almost the same maximum efficiency values between the given range of advance coefficients except DTMB 4382 propeller. This propeller has a slightly lower maximum efficiency value. On the other hand, under cavitating conditions, the skew has a positive effect for higher loading conditions. Higher skew angle causes lower cavity area and thus volume. For lower loading conditions, skew does not matter anymore.

5. References

[1] Hu, J., Huang, Q., Guo, T., Geng, C. and Sun, S. (2017). Cavitation simulation of highly skewed propellers. 2nd International Conference on Architectural Engineering and New Materials (ICAENM 2017), Feb. 25-26, Guangzhou, China, 218-226.

[2] Zhu, Z.F. (2013). Numerical study of the effect of propellers skew on cavitation performance. Advanced Materials Research, Vol. 705: 405-409.

[3] Ji, B., Luo, X., Wang, X., Peng, X., Wu, Y. and Xu, H. (2011). Unsteady numerical simulation of cavitating turbulent flow around a highly skewed model marine propeller. Journal of Fluids Engineering, Vol. 133: 011102-011102-8. doi:10.1115/1.4003355.

[4] Wang, L.Z., Guo, C.Y., Su, Y.M and Wu, T.C. (2018). A numerical study on the correlation between the evolution of propeller trailing vortex wake and skew of propellers. International journal of Naval Architecture and Ocean Engineering, 10: 212-224.

[5] Zhu, Z.F. (2015). Numerical study on characterisitc correlation between cavitating flow and skew of ship propellers. Ocean Engineering, 99: 63-71.

[6] Ghasseni, H. and Ghadimi, P. (2011). Numerical analysis of the high skew propeller of an underwater vehicle. Journal of Marine Science and Application, 10 (3): 289e299.

[7] Baek, D.G., Yoon, H.S., Jung, J.H., Kim, S.K. and Paik, B.G. (2015). Effects of the advance ratio on the evolution of a propeller wake. Computers and Fluids, 118: 32-43.

[8] Bal, S. (2010). Hydrodynamic performance of ship propellers. Shipyard, No: 17: 32-36.

[9] Kerwin, J.E. and Lee, C-S. (1978). Prediction of steady and unsteady marine propeller performance by numerical lifting-surface theory. Trans. SNAME, 86.

[10] Lee, C-S. (1979). Prediction of steady and unsteady performance of marine propellers with or without cavitation by numerical lifting surface theory, PhD thesis, M.I.T., Department of Ocean Engineering, USA.

[11] Kinnas, S.A., Griffin, P., Choi, J-K. and Kosal, E. (1998). Automated design of propulsor blades for high-speed ocean vehicle applications. Trans. SNAME, 106.

[12] Greeley, D.S. and Kerwin, J.E. (1982). Numerical methods for propeller design and analysis in steady flow. Trans. SNAME, 90.

[13] Szantyr, J.A. (1994). A Method for analysis of cavitating marine propellers in non-uniform flow. International Shipbuilding Progress, 41: 223-242.

[14] Celik, F. and Guner, M. (2006). Improved lifting line method for marine propeller. Marine Technology, SNAME, 43: 100-113.

[15] Bal, S. and Guner, M. (2009). Performance analysis of podded propulsors. Ocean Engineering, 36: 556-563.

[16] Bal, S. (2011). A method for optimum cavitating ship propellers. Turkish Journal of Engineering and Environmental Sciences, 35:139-158.

[17] Bal, S. (2011). A practical technique for improvement of open water propeller performance. Proceedings of the Institution of Mechanical Engineers, Part M, Journal of Engineering for the Maritime Environment, 225: 375-386.

[18] Griffin, P.E. and Kinnas, S.A. (1998). A design method for high-speed propulsor blades. Journal of Fluids Engineering, 120: 556–562.

[19] Kerwin, J.E. (2001). Hydrofoils and propellers. Lecture Notes, Department of Ocean Engineering, Massachusettes Institute Technology, USA.

[20] Carlton, J.S. (2012). Marine propellers and propulsion. Oxford: Elsevier (Butterworth-Heinmann) Publ.

[21] Boswell, R.J. (1971). Design, cavitation performance and open water performance of a seriesof research skewed propellers. NSRDC Report No: 3339, USA.

[22] Brizzolara, S., Villa, D. and Gaggero, S. (2008). A systematic comparison between RANS and panel methods for propeller analysis. Proc. of 8th International Conference on Hydrodynamics, Nantes, France, Sep. 30-Oct. 3.

Received: 05 December 2018 *Accepted: 07 February 2019* *DOI ID: 10.5505/jems.2019.30922*

Journal of ETA Maritime Science

JEMS JOURNAL

Corresponding Author: Kubilay BAYRAMOĞLU

Numerical and Theoretical Thermal Analysis of Ship Provision Refrigeration System

Kubilay BAYRAMOĞLU, Semih YILMAZ, Kerim Deniz KAYA

Dokuz Eylül University, Maritime Faculty, Turkey
kubilay.bayramoglu@deu.edu.tr; ORCID ID: https://orcid.org/0000-0002-5838-6132
semih.yilmaz@deu.edu.tr; ORCID ID: https://orcid.org/0000-0002-0791-4476
deniz.kaya@deu.edu.tr; ORCID ID: https://orcid.org/0000-0002-0985-2280

Abstract

The freezer system on ships involves provisions where meat, fish, vegetables etc. are cooled down. Provision room is one of the essential features on ships for the preservation of food. The size of the cooling chamber varies according to the length of the ship and the number of personnel. Under the scope of the study, a room with volume of 15 m^3 (H x L x W, 2.5 x 3 x 2 m.) has been designed for the preservation of the meat. Boundary conditions which are determined for numerical and theoretical analysis in provision room have been chosen considering existing ship conditions. Refrigeration load, temperature distribution and flow streamline to keep the meat at the desired temperature in the provision room have been analyzed for one hour working period. Within this time interval, average meat domain and air temperature drop have been found as 4.33 K and 13 K, respectively. CFD analysis and theoretical calculation results have been compared. The results have found to be in agreement with acceptable errors less than 10%. The outputs from analysis show that refrigeration unit provides suitable temperature decrease within determined time interval.

Keywords: *Refrigeration Systems, Computational Fluid Dynamics, Ship Provision Room.*

Gemi Kumanya Odasının Sayısal ve Teorik Termal Analizi

Öz

Gemilerde et, balık ve meyve sebze gibi kumanyaların bulunduğu bölmelerin soğutularak muhafaza edildiği soğutma sistemleri mevcuttur. Gemilerde bulunan soğutma sistemi yiyeceklerin bozulmadan muhafaza edildiği temel ve gerekli yapılardan biridir. Bu soğutma odaları geminin boyuna ve bulunan mürettebat sayısına göre farklı boyutlara sahip olabilir. Çalışmada, 15 m^3 (Y x U x G, 2.5 x 3 x 2 m.) boyutlarında karkas etlerin korunması amacıyla bir oda tasarlanmıştır. Teorik ve sayısal çalışma için sınır koşulları uygun gemi koşulları düşünülerek belirlenmiştir. Soğutma odasında yer alan etin sıcaklığını istenilen değerde tutmak için soğutma yükü, sıcaklık dağılımı ve akış hattı bir saat süreyle zamana bağlı olarak analiz edilmiştir. Bu zaman aralığı için et kontrol hacmi ve soğutma odası havasındaki sıcaklık düşüş değeri sırasıyla 4.33 K ve 13 K olarak bulunmuştur. Çalışmada, sayısal analiz ve teorik hesaplama sonuçları karşılaştırılmıştır. Sonuçlar, %10 değerinden daha az bir hata payı ile doğrulanmıştır. Analiz çıktıları, soğutma odası için soğutma ünitesinin belirlenen zaman aralığında uygun sıcaklık düşümünü sağladığını göstermiştir.

Anahtar Kelimeler: *Soğutma Sistemi, Hesaplamalı Akışkanlar Dinamiği, Gemi Kumanya Odası.*

To cite this article: Bayramoğlu, K., Yılmaz, S. & Kaya, K. D. (2019). Numerical and Theoretical Thermal Analysis of Ship Provision Refrigeration System. *Journal of ETA Maritime Science*, 7(2), 137-149.
To link to this article: https://dx.doi.org/10.5505/jems.2019.30922

1. Introduction

Cooling rooms where food is kept without degeneration on ships are generally designed as three separate rooms. The first one of these rooms is called dry provision where dry foods such as potatoes are preserved. Dry provisions should not be cooled too much. Only, these rooms must be dehumidified. The other two rooms in the provision are the rooms where food such as meat and fish are stored [1].

The lack of effective food cooling systems causes changes in the structure of food [2]. Many ship provision products require refrigeration. Food should be stored at low temperatures to ensure that food on ships is protected from microscopic organisms that can cause adverse effects, such as bacteria. Frozen foods such as meat must be frozen in order to protect their initial properties while being carried inside the freezer for a long-term [3]. The meat storage temperature of the room should be lower than -12 ˚C degrees. Reaching such lower temperatures in these rooms creates various problems inside the ship environment [1, 4].

Refrigeration room is commonly designed for keeping foods at a certain temperature to convenient freshness, quality, safety, and shelf life. For this reason, the refrigeration system generally requires excellent optimization in ships. There are several factors that affect the cooling units such as indoor and outdoor operating conditions. Provision room has three main components; room cavity, insulated walls and refrigeration units. Airflow and heat transfer calculation inside the provision room is a very challenging task [5].

There are many approaches to solving refrigeration problems. Nowadays, experimental tests and computational analyses are mostly preferred by researchers. Experimental tests require plenty of time, expensive equipment and usually applied to simple problems [5-10]. The promising approach from computational analyses is computational fluid dynamics (CFD). The CFD model is the paramount option for the prediction and analysis of refrigeration systems [11]. CFD employs finite volume and finite element method. These methods convert all governing equations into algebraic form and allow them to be numerically solved [12].

Zhijuan et al. [13] investigated the relationship between food package temperature and internal environment. This study revealed that the temperature of the cooling cabinet is affected by light, outdoor airflow, and partial humidity. Ge et al. [11] applied 2D steady-state CFD model to investigate the airflow dynamics and heat transfer for airflow from cooling coil air off-to air-on and also numerical simulation results were tested with experimental results. Tsang and Yung [14] evaluated the factors that emerge freezing capacity loss. The researchers compared the regression model taken by experimental data with the theoretical formulation efficiency. Aste et al. [15] presented a comprehensive review of scientific and grey literature on active refrigeration technologies for food preservation. Glavan et al. [16] studied hybrid model of a refrigeration system. This system includes many different refrigeration models such as refrigerated display case dynamics, food dynamics, evaporation model and ice formation model. 3-D simulation model of full refrigeration cabinet was designed by Wang et al. [5]. CFD simulation of refrigeration model showed temperature distribution in refrigeration cabinet. Jolly et al. [17] studied a shipping container refrigeration system with a mathematical model and investigated thermal performance for full load simulation. Getahun et al. [18] developed and validated a CFD model for a refrigerated shipping container with a porous medium approach. An open refrigerated display cabinet (ORDC) was investigated by Carvalho et al. [19] with airflow and heat transfer CFD modelling.

In the present study, fluid flow and heat transfer modelling of refrigerated provision room is performed by CFD with commercial software ANSYS Fluent® [20]. The theoretical model is created by heat transfer and refrigeration load calculation equations. Comprehensive numerical model findings are compared with theoretical results. Besides that, temperature profiles in room air and meat are obtained in 3D space. Hence, the effect of location on the temperature profile in meat is clearly seen. Temperature results will help not only for proper storage and management of meat but also for optimum location of refrigeration units in places with different wall temperatures.

2. Description of Provision Room

3D model of the provision room which is cooled down to -10 °C with refrigeration unit and 3 x 3 array hanged meat carcass are represented. Meat domain is designed by closest geometric shape shown in Figure 1. The inner structure of meat solid domain is assumed to be homogenous.

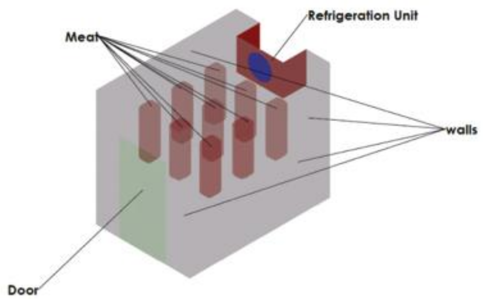


Figure 1. Provision Room 3D Detail

Provision room geometry is designed with 2.5 m height, 3 m length and 2 m width considering the systems currently used on ships. Total weight of meat domains in simulation is determined to be 665 kg. The distance between the meat domains is 400 mm, placed in the middle of the room depending on the location of the evaporator. The position of the door to the provision room is defined as far away from the evaporator as possible in the computational domain.

The refrigeration unit is selected as single fan evaporator in the provision room the technical specifications of which are indicated in Table 1.

Table 1. *Refrigeration Unit (Evaporator) Technical Specifications*

Technical Specification	Values
Airflow rate [m^3/h]	6000
Fan diameter [mm]	500
Surface [m^2]	26.1
Average capacity [W]	4600
Defrost electrical heaters [W]	10 x 500
Dimensions (H x L x W) [mm]	670 x 980 x 720

Generally, refrigerated room walls are insulated by sandwich panels in which polyurethane foam thicknesses can change according to heat insulation capacity, depending on the conditions of the region and the intended use of the structure. The sandwich panels are coated with metal sheets in compliance with TS EN ISO 6946 standards. The thickness of the enclosing plate is 0.5 mm and the thickness of the insulation walls (polyurethane) is 50 mm. The section of the walls is shown in Figure 2.

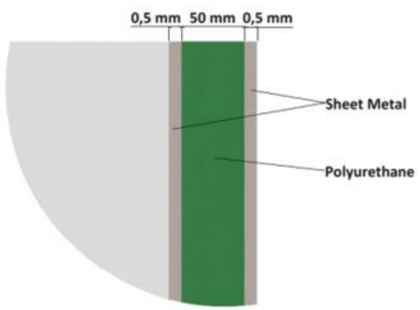


Figure 2. Provision Room Wall Section

3. Theoretical Model

3.1. Heat Dissipation Over Walls

The heat exchange phenomenon takes place in many places of the cooling system when the cooling process is performed. In provision room walls, heat transfer calculation is made by thermal resistance network approach. Although the provision room is three-dimensional, approximate solutions can be achieved by assuming one-dimensional heat transfer [21]. In refrigeration systems, one-dimensional heat transfer is calculated by the following formula [22]:

$$Q=\frac{T_{\infty}-T_{\infty 2}}{\sum R_t} \quad (W) \tag{1}$$

$$\sum R_t=\frac{1}{h_1 A}+\frac{L_1}{k_1 A}+\frac{L_2}{k_2 A}+\frac{L_3}{k_3 A}+\frac{1}{h_2 A} \quad (K/W) \tag{2}$$

Provision room wall layers are made from two different materials. Heat transfer resistance network of walls is shown in Figure 3.

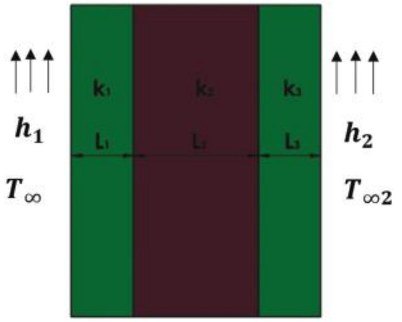


Figure 3. *Equivalent Thermal Circuit for A Series of Composite Wall*

Total heat transfer coefficient (U) is defined for composite material walls with this formula:

$$U=\frac{1}{\sum R_t A} \quad (W/m^2{\cdot}K) \tag{3}$$

3.2. Refrigeration Load Calculation

The purpose of the refrigeration load calculation is to select proper refrigeration system components in an economical manner. The correct choice of the refrigeration components will bring seamless and maintenance-free operation in provision refrigeration systems. The gains that resulted from heat form refrigeration loads. These loads can be categorized into four groups as follows [4]:

- Heat dissipation over walls, ceiling, and floor,
- Infiltration heat is caused by the external warm environment,
- Foods inside the cooled provision room,
- Heat sources like working humans, illumination, motors, etc.

It is desirable that the transmitted heat is very small in order to prevent the heat energy in the room from leaking out to the outside as described in the above section. In order to calculate the transmitted heat, the cooling room insulation thickness and type, the construction of the building, the physical properties of the volume to be cooled, the room volume and the volume effect outside must be determined in advance. Decreasing the coefficient of thermal conductivity and the cooling load can be achieved by increasing the insulation thickness but this thickness increases the cost and reduces the food storage volume [4].

Each time the cold room door is opened and closed, some external hot air enters the cold room creating an additional cooling load. It is possible to detect this load correctly, by knowing the actual operating conditions. Experimental studies have shown that the infiltration load depends on room volume in cooling applications. The influence of the infiltration load was neglected because the door of the ship provision room door was not used frequently (once a week) during operation.

Heat emerges from various species of foods that are stored in the ship provision room. This heat is the most important and largest part of the cooling load. Analytical heat transfer analysis can be applied with Fourier series for only very limited positions due to the complexity of the three-dimensional transient heat transfer. In short, the determination of the cooling time depends on the type of the object to be cooled, the shape, the speed of the cold air given by the cooler, air temperature and distribution in the cold room and also the type of the cooling application.

The cooling load which is brought by the foods placed in the provision room is divided into four phases:

- Cooling over freezing temperature
- Latent heat to be taken during freezing
- Taking maturation heat of foods
- Super cooling after freezing

In this study, the provision room is kept at a certain temperature. The frozen meat is brought from outside to the provision room. Thus, super cooling after freezing is taken into consideration on analytical analysis as shown in the following equation:

$$Q_{fr} = \frac{m(kg)\cdot c_{meat}\,(kJ/kg\cdot K)\cdot \Delta T}{\text{Cooling Time(s)}} \quad (kW) \tag{4}$$

Lighting heat load is calculated according to lighting fixture type and operation time:

$$Q_{lf} = \frac{\text{Lighting Power (W) x Lighting Time(h)}}{\text{Operation Time (h)}} \quad (kW) \tag{5}$$

Another aspect in the refrigeration system during a long-time operation is defrosting. Defrost is caused by accumulated clogging of the outdoor heat exchanger (condenser). Airflow rate decrease of the evaporator fan trigger heat transfer performance drop in the cooling system [23, 24]. The electric defrost heaters in the cooled volume are located on the evaporator. Given the power of these heaters in Watt and the number of working hours per day, the heat which is emerged during the defrost can be found by the following equation [4]:

$$Q_{Def} = \text{n x heat power x H x F (W)} \tag{6}$$

Where; n, number of defrost heater, H, running time of cooling (h/day) and F, defrost factor which is identified as a part of electrical energy entering the cooling room as heat load. Refrigeration load can be calculated with the following equation:

$$Q_t = Q + Q_{fr} + Q_{lf} + Q_{Def} \tag{7}$$

4. Numerical Model

Numerical solutions of the physical process such as heat transfer, fluid flow, and other related process have been expressed in a mathematical form which is derived by governing differential equations. A computer program is often needed because it is difficult to solve these equations numerically [25]. A steady-state 3-D CFD model is solved using the commercial ANSYS Fluent® software package. This software is used to analyse the mathematical description of physical phenomena [26].

4.1. Governing Equations

In this study, incompressible flows are used for analysis and CFD solves conservation equations for mass and momentum. The conservation equations are relevant to turbulence modelling and heat transfer [20, 27]. The continuity equation can be written as follows;

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\vec{v}) = 0 \tag{8}$$

Where, ρ is the density and $\vec{v}$ is the velocity. In addition to above equation, gravity term is added in the body force. Conservation of momentum differential equation is given for a non-accelerating reference frame as follows [20, 25, 28].

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla\cdot(\rho\vec{v}\vec{v}) = -\nabla p + \nabla\cdot(\vec{\tau}) + \rho\vec{g} + \vec{F} \tag{9}$$

$$\frac{\partial}{\partial t}(\rho H) + \nabla(\rho\vec{v}H) = \nabla\left(\frac{k}{c_p}\nabla H\right) \tag{10}$$

where, p, $\vec{\tau}$, $\rho\vec{g}$, $\vec{F}$, H, T, k, and c_p static pressure, stress tensor, gravitational body force, external body forces, enthalpy, temperature, thermal conductivity and specific heat of air, respectively.

The standard k-ω turbulence model which is based on transport equations for the turbulence kinetic energy (k) and the specific dissipation rate (ω) has been used in the present study.

4.2. Mesh and Boundary Conditions

Three-dimensional fluid domain and computational mesh of the provision room is shown in Figure 4. In this model, boundaries of the refrigeration unit and meat have been intensified to take the most precise results. 5 boundary layers with 1.2 growth rate has been applied on meat surfaces. Meat domain and room domain has different element sizes on their bodies.

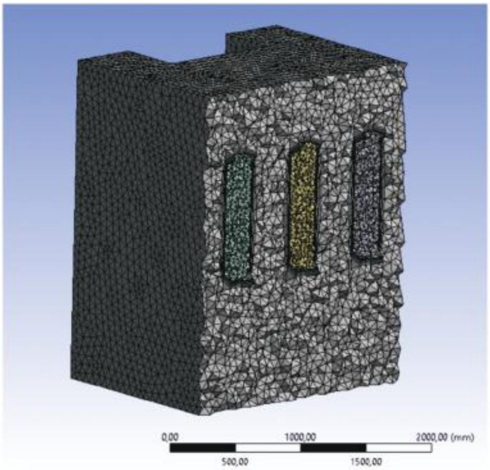


Figure 4. *Computational Mesh*

Ansys Meshing commercial software has been used in mesh generation. Mesh dependence checks have been carried out for three different mesh models with various mesh densities. Temperature distribution on each meat domain has been calculated for 62243, 94356 and 456003 element numbers at 3600s. These numerical results show that the solution is independent of the mesh size both in solid and fluid regions as shown in Figure 5. According to effective use of computer resources and time, the grid that has 94356 elements is selected for the analysis. Mesh domain also contains structural and unstructured elements.

Figure 5. *Grid Independency of Solid-Fluid Regions for 3600 s*

Second-order implicit time stepping method has been used with changeable step sizes of 0.02 and 0.2 up to 3600 s. A hundred iterations have been performed for each time step to achieve normalized residuals in the range of single precision machine accuracy. Mesh specifications are applied to the model are shown in Table 2.

Table 2. *Mesh Specifications*

Technical Specification	Values
Number of elements	94356
Element quality	0.76226
Mesh types	Tetrahedral and hexahedral mesh

The creation of the appropriate numerical model in computational fluid dynamics applications is a very important factor. It is necessary to define the boundary conditions correctly on the created model in order to obtain correct results. In this study, the shape of three-dimensional CFD model for the provision room is shown in Figure 6.

To calculate the solutions, boundary conditions and material properties are applied in CFD software. Boundary conditions which have been determined considering provision room conditions are indicated in Table 3.

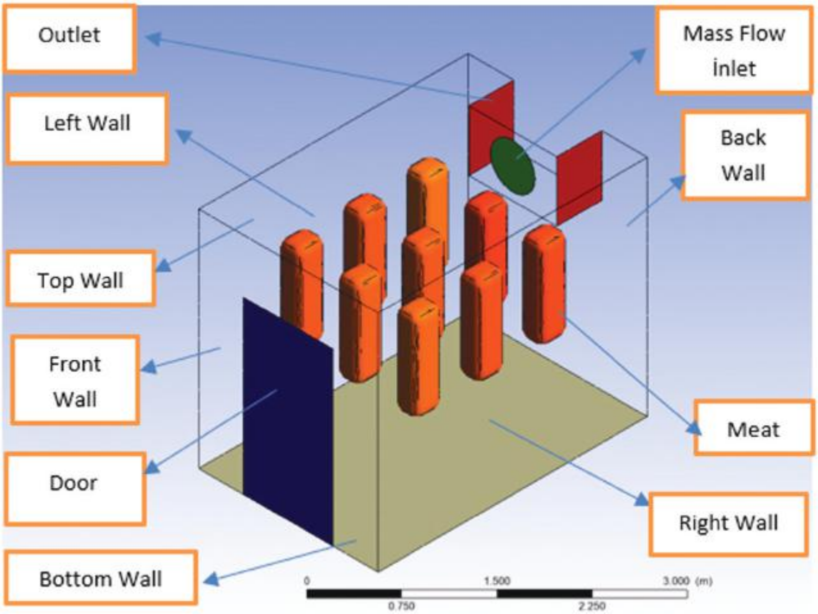


Figure 6. *Boundary Conditions*

Table 3. *Boundary Conditions*

Types	Values
Mass flow inlet [kg/s]	2.04
Inlet temperature (°K)	259
Outlet	Pressure - Outlet
Wall heat transfer coefficient (W/m^2°K)	0.412
Wall (left, right, front, back and door) outside temperature (°K)	313
Wall (bottom and top) outside temperature (°K)	303
Provision room initial temperature (°K)	273
Meat initial temperature (°K)	269

5. Results and Discussion

In ship provision refrigeration system, transport temperature of the food system must be at least -4 ^{0}C (~269 K) to prevent food from spoiling. While setting initial conditions, provision room and blower (evaporator) inlet air temperature have been accepted to be 273 K and 259 K respectively. Data set values are taken by sample mid-planes. Locations of these planes are shown in the domain by Figure 7.

Temperature profile is a very important parameter for thermal uniformity in refrigeration analyses. In Figure 8, temperature distribution which is depending on determined operating conditions is calculated numerically for one hour working period. Plots are created with time intervals of 600 s, 1200 s, 1800 s, 2400 s, 3000 s and 3600 s, respectively.

Initially, the provision room and meat domain temperature are set to be 273 K and 269 K, respectively. According to temperature data at mid-plane 1, meat

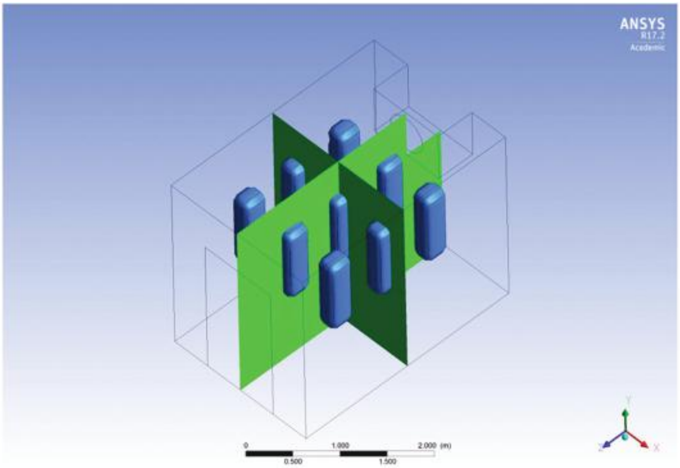


Figure 7. *Dataset Plane Locations*

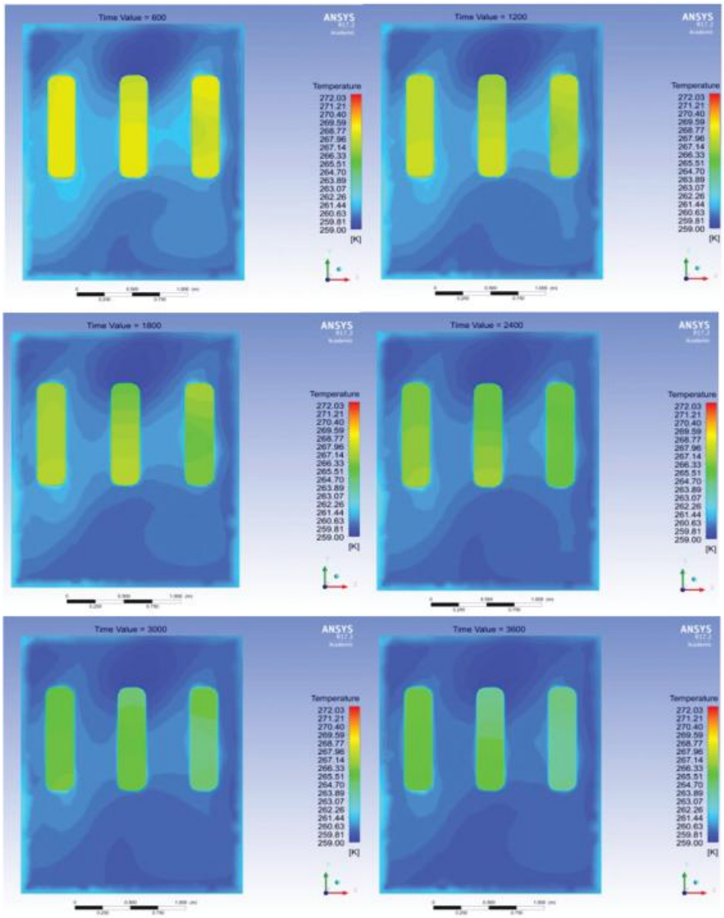


Figure 8. *Temperature Distribution of Specified Time Intervals*

domain temperature decreases slowly over time after one-hour period. Meantime, average meat domain temperature drop is 4.33 K.

Similarly, meat domain temperature change is shown at mid-plane 2 in Figure 9. Temperature near the inlet is less than the provision room bottom side and also the temperature decreases because of the flow around the evaporator unit. Over one-hour period, average air temperature value has decreased by 13 K compared to the initial condition in the provision room, but the thermal uniformity could not be achieved.

Below the meat array since the cold air is blown over them. However, the velocity at the evaporator outlet is remarkably lower than the velocity at the evaporator inlet due to frictional loss of air through the circulation inside the room. After evaporator fan starts, air

begins to flow over meat domain and turns back to evaporator outlet. At t=1800 s, velocity profile of provision room is shown in Figure 10.

According to the analysis results, the highest velocity value occurs at the circumference of evaporator. Labelling for three dataset planes are shown with letters a, b, and c with the distance from refrigeration unit in Figure 11.

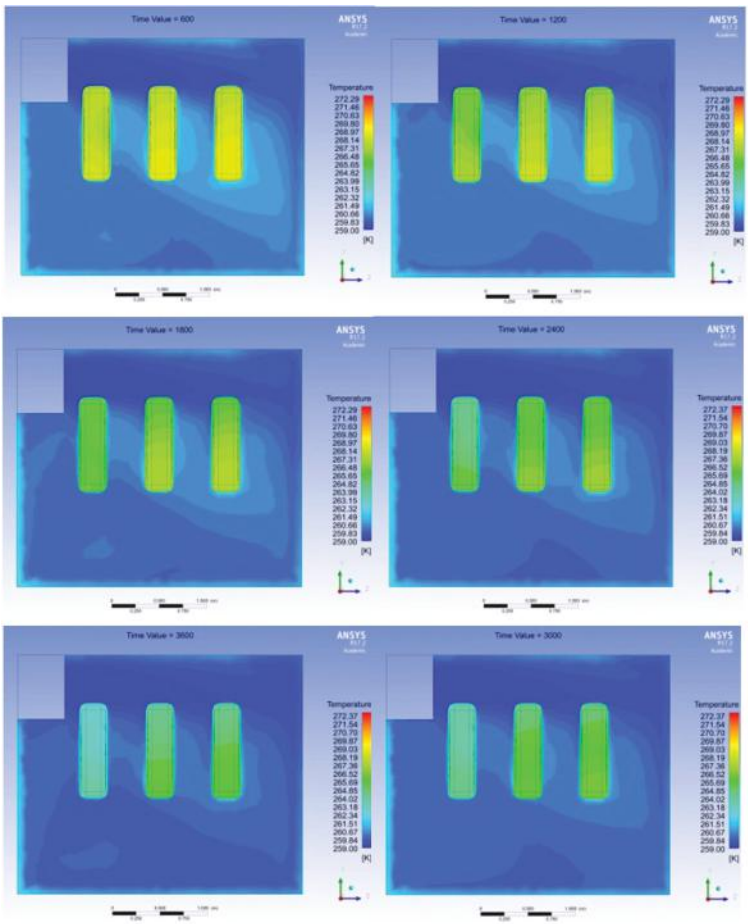


Figure 9. *Temperature Distribution of Specified Time Intervals for mid-plane 2*

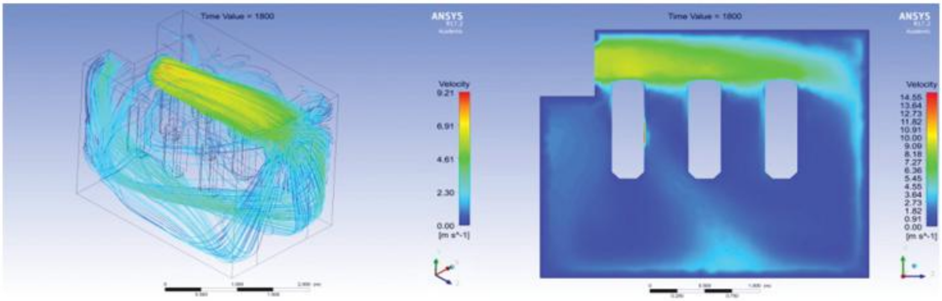


Figure 10. *Velocity Profile of Provision Room (at t=1800 s)*

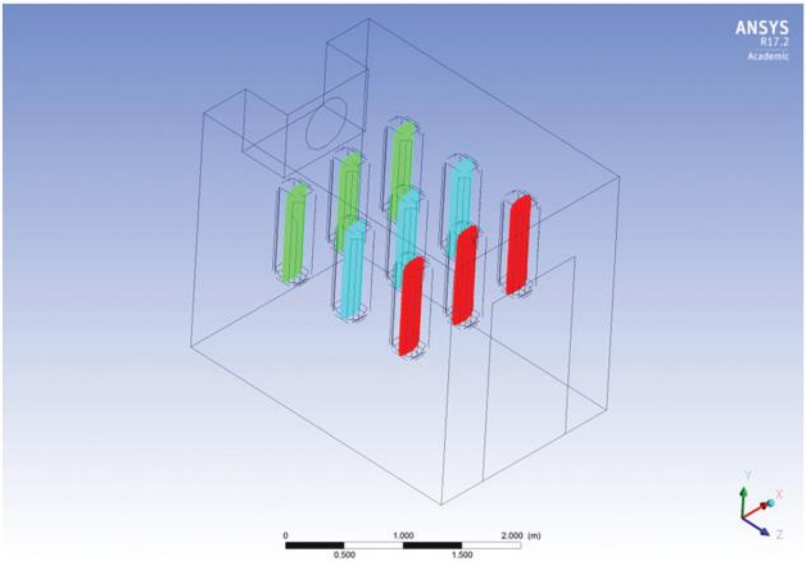


Figure 11. *Labels for Dataset Plane Locations for Meat Domains*

Average temperature distributions in three dataset planes with their corresponding labels are shown in Figure 12. Temperatures shown are averaged in space at the time of 3600 s. It is observed that average temperature values for each plane are different from each other data received from the numerical analysis due to flow distribution in the provision room. The temperature values calculated for three different planes over one-hour working period are demonstrated in Figure 12.

Inside the provision room for a, b, c dataset planes at 3600 s., meat domain average temperatures decrease from 269 K to 264.76 K, 264.83 K and 264.50 K, respectively. According to these results, velocity streamlines of inlet fan, evaporator and meat positions have an influence on average temperatures of meat domains with respect to time.

Besides, CFD analysis and theoretical calculation results are compared and demonstrated in Table 4. According to heat transfer results, it can clearly be seen that analytical and numerical results are in good agreement with acceptable errors for each boundary condition. Theoretically calculated values of lighting and defrost are omitted in a numerical approach.

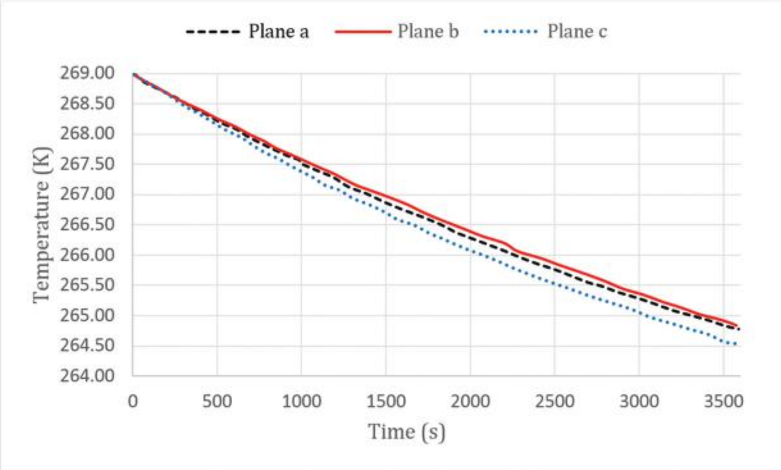


Figure 12. *Meat Domain Temperature Profiles for a, b and c Planes*

Table 4. *Heat Transfer on Boundary Conditions*

Boundary Conditions	Analytical Results (W)	Numerical Results (W)	Error (%)
Meat (surface)	1355.17	1242.1	8.34
Wall (left and right)	334.33	320.27	4.20
Wall (back)	96.73	91.34	5.57
Wall (front)	111.44	108.45	2.69
Wall (top)	99.89	96.14	3.75
Wall (bottom)	108.97	103.38	5.13

6. Conclusion

In this study, a three-dimensional ship provision system domain is analysed with analytical and numerical methods over transient operating conditions for one hour working period. 3D CFD Model has been generated with ANSYS® Fluent commercial software including airflow and heat transfer study in ship provision room.

Heat transfer on boundaries, temperature and velocity profiles on mid-planes are calculated over computational domain. According to the numerical results, average meat domain temperature and air temperature drop have been found to be 4.33 K and 13 K, respectively for one hour working period. However, it is observed that all meat domain average temperature changes are not the same inside the provision room.

The computed heat transfer for the present provision room geometry is compared with the analytical results. It can clearly be seen that CFD model heat transfer results, which are validated with theoretical findings, give less than 10% error.

This study shows that ship provision room temperature decreases over one hour working period depending on determined cooling capacity. Temperature decrease with respect to time is usable for choosing a suitable refrigeration system. Besides that, it leads to further improvements in the performance of ship provision room system designs. We suggest that further parametric studies are needed to investigate on refrigeration unit location inside the provision room.

References

[1] Demirel, K. (2014). Gemi yardımcı makineleri ve Sistemleri. İstanbul: Birsen yayıncılık.

[2] Kayansayan, N., Alptekin, E., and Ezan, M.A. (2017). Thermal analysis of airflow inside a refrigerated container. International Journal of Refrigeration. 84 76–91.

[3] Pamuk, M.T., Savaş, A. (2017). A practical tool for evaluating refrigeration System using R-134a. Journal of ETA Maritime Science. 2017:5:1:69-79

[4] Özkol, N. (2016). Uygulamalı Soğutma Tekniği. Ankara: TMMOB Makine Mühendisleri Odası.

[5] Wang, L., Zhang, L., and Guoping, L. (2015). A CFD Simulation of 3D Airflow and Temperature Variation in Refrigeration Cabinet. Procedia Engineering, 2015:102:1599-1611.

[6] Marinetti, S., Cavazzini, G., Fedele, L., Zan, F., Schiesaro, P. (2012). Air velocity distribution analysis in the air duct of a display cabinet by PIV technique. International Journal of Refrigeration, 35:2312-2331.

[7] Yashar, D., Cho, H., Domanski, P. (2008). Measurement of air-velocity profiles for finned-tube heat exchangers using particle image velocimetry, in: International Refrigeration and Air Conditioning, Purdue University.

[8] Chen, Y., Yuan, X. (2005). Experimental study of the performance of single-band air curtains for a multi-deck refrigerated display cabinet, Journal of Food Engineering, 69 261-267.

[9] Field, B., Loth, E. (2006). Entrainment of refrigerated air curtains down a wall, Experimental Thermal and Fluid Science, 30:175-184.

[10] Yu, K., Ding, G., and Chen, T. (2009). Experimental investigation on a vertical display cabinet with central air supply, Energy Conversion and Management, 50:2257-2265.

[11] Ge, Y. T., Tassou, S. A. And Hadawey, A. (2010). Simulation of multi-deck medium temperature display cabinets with the integration of CFD and cooling coil models. Applied Energy. 87:10:3178-3188

[12] Ruangtrakoon, N., Thongtip, T., Aphornratana, S. and Sriveerakul, T. (2013). CFD simulation on the effect of primary nozzle geometries for a steam ejector in refrigeration cycle. international Journal of Thermal Sciences. 63:133-145

[13] Zhijuan, C., Xuehong, W., Yanli, L., Qiuyang, M. And Wenhui, Z. (2013). Numerical simulation on the food package temperature in refrigerated display cabinet influenced by indoor environment. Advances in Mechanical Engineering. 2013:7

[14] Tsang, A. H. F. and Yung, W. K. (2017). Development of an Adaptive Food Preservation System for food quality and energy efficiency enhancement. International Journal of Refrigeration, 76, 342–355.

[15] Aste, N., Del Pero, C., and Leonforte, F. (2016). Active refrigeration technologies for food preservation in humanitarian context - A review. Sustainable Energy Technologies and Assessments. 150-160

[16] Glavan, M., Gradišar, D., Invitto, S., Humar, I., Juričić, J., Pianese, C., and Vrančić, D. (2016). Cost optimisation of supermarket refrigeration system with hybrid model. Applied Thermal Engineering, 103, 56–66.

[17] Jolly, P. G., Tso, C. P., Wong, Y. W., & Ng, S. M. (2000). Simulation and measurement on the full-load performance of a refrigeration system in a shipping container. International Journal of Refrigeration, 23(2), 112–126.

[18] Getahun, S., Ambaw, A., Delele, M., Meyer, C. J. And Opara, U. L. (2017). Analysis of airflow and heat transfer inside fruit packed refrigerated shipping container: Part I Model development and validation. Journal of Food Engineering, 203, 58–68.
[19] Carvalho, C. C. de, Novaes, A. G., & Lima Júnior, O. F. (2010). a Logística Da Distribuição De Produtos Alimentícios Refrigerados: Problemas E Perspectivas No Contexto Brasileiro. XXVI Anpet, 1969–1980.
[20] Ansys Fluent User's Guide. (2016). ANSYS Inc., Release 17.2
[21] Çengel, Y.A. and Ghajar, A.J. (2015). Heat and Mass Transfer. New York: McGraw-Hill Education.
[22] Bergman, T.L., Lavıne, A.S., Incropera, F.P. and Dewitt, D.P. (2011). Fundamentals of Heat and Mass Transfer. USA: John Wiley & Son
[23] Kim, J., Choi, H. J., and Kim, K. C. (2015). A combined Dual Hot-Gas Bypass Defrosting method with accumulator heater for an air-to-air heat pump in cold region. Applied Energy. 147, 344–352.
[24] Song M, Xu X, Mao N, Deng S, Xu Y. 2017. Energy transfer procession in an air source heat pump unit during defrosting. Applied Energy. 204:679–689.
[25] Patankar, S.V. (1980). Numerical Heat transfer and Fluid Flow. USA: Hemisphere Publising Corparation.
[26] Parpas, D., Amaris, C., Sun, J., Tsamos, K. M., and Tassou, S. A. (2017). Numerical study of air temperature distribution and refrigeration systems coupling for chilled food processing facilities. Energy Procedia, 123, 156–163.
[27] Tanaka, F., Konishi, Y., Kuroki, Y., Hamanaka, D., and Uchino, T. (2012). The use of CFD to improve the performance of a partially loaded cold store. Journal of Food Process Engineering, 35(6), 874–880.
[28] Batchelor, G.K. (1967). An Introduction to Fluid Dynamics. England: Cambridge University Press.

This Page Intentionally Left Blank

Original Research (AR) *Demirel / JEMS, 2019; 7(2): 151-163*

Received: 10 February 2019 *Accepted: 11 March 2019* *DOI ID: 10.5505/jems.2019.49379*

Journal of ETA Maritime Science

JEMS JOURNAL

Corresponding Author: Hakan DEMİREL

Prediction of Human Error Probability for Possible Gas Turbine Faults in Marine Engineering

Hakan DEMİREL

Zonguldak Bülent Ecevit University, Maritime Faculty, Turkey
hakandemirel@beun.edu.tr; ORCID ID: https://orcid.org/0000-0002-7579-7064

Abstract
For all areas where operational activities exist, human error possibilities are of critical importance. In this sense, maintenance, management and monitoring of all components in ships powered by gas turbine systems is a condition that must be observed. At this point, the importance of human impact is great and plays a critical role. In this study, the probabilities of human error on the 14 critical faults described in the literature for gas turbine components are calculated by the CREAM method in the sense of expert opinions. The results clearly indicate the importance of human impact on faults, and guide the technical personnel to be employed on board ship during the operation. This study provides the basis for further studies in this area.

Keywords: *Marine Engineering, Gas Turbine, Human Error Prediction, CREAM.*

Deniz Mühendisliğinde Olası Gaz Türbini Arızaları için İnsan Hatası Olasılığının Tahmini

Öz
Operasyonel faaliyetlerin olduğu tüm alanlar için insan hatası olasılıkları kritik öneme sahiptir. Bu anlamda gaz türbin sistemleri ile seyir eden gemilerdeki bütün bileşenlerin bakımı, yönetimi ve izlenmesi gerekli bir durumdur. Bu noktada insan etkisinin önemi büyük ve kritik bir rol oynamaktadır. Bu çalışmada, gaz türbini bileşenleri için literatürde ifade edilen 14 kritik arızadaki insan hatası olasılığı, uzman görüşleri alınarak, CREAM yöntemi ile hesaplanmıştır. Elde edilen sonuçlar, arızalar üzerinde insan etkisinin ne kadar önemli olduğunu net bir şekilde ifade etmektedir ve operasyon boyunca gemide çalıştırılacak teknik personele dikkat etmesi gereken durumlar açısından yol gösterici niteliktedir. Bu çalışma bu alanda yapılacak daha sonraki çalışmalar için temel oluşturmaktadır.

Anahtar Kelimeler: *Deniz Mühendisliği, Gaz Türbini, İnsan Hatası Tahmini, CREAM.*

To cite this article: Demirel, H. (2019). Prediction of Human Error Probability for Possible Gas Turbine Faults in Marine Engineering. *Journal of ETA Maritime Science*, 7(2), 151-163.
To link to this article: https://dx.doi.org/10.5505/jems.2019.49379

1. Introduction

Human error analysis studies are increasing rapidly and many field applications are being made [1]. The problems that arise in industrial facilities due to human-induced faults make this situation even more complicated [2]. Human factor plays an important role in industrial reliability and safety analysis. At this point, any accidental loss that may occur in real life must be considered.

When a component of an industrial plant or system is examined and risk assessed, a structure that identifies all the points of the system arises. This relationship is clarified by determining the boundaries of the accepted system and revealing its functional properties. The operation and maintenance of the system is an important part of this analysis.

Gas turbine systems are preferred internal combustion engines in marine vehicles and power plants [3]. These systems require manufacturing precision and qualified workforce. There is a need to build a specific point of view for gas turbines. Thus, new situations that may occur in malfunctioning or undamaged engines are taken into consideration. In most cases, it is known that faults cause serious damage and a significant loss of capital investment. In this case, it is very clear that the gas turbine components must be handled carefully. The types and severity of faults in gas turbine components are different from those due to operating conditions.

Maintenance personnel has a critical role in the safe operation of gas turbine components. It is known that most human errors occur in the course of the maintenance of equipment. For this reason, it is significant that focusing on the human errors during the maintenance phase. By analyzing the errors that people make on the system, the new system structures can be developed to reduce both error occurrence and effects.

The aim of this study is to determine the probabilities of human error on possible faults in gas turbine systems. It is emphasized by the opinions of experts in the field and the Cream method that the determined probabilities are important for the technical personnel involved in the gas turbine operations.

2. Literature Review

Gas turbine technology involves complex technical systems that are managed by human influence. This clearly indicates the impact of people on the safe operation of the system. Recently, analysis of large accidents has revealed that human error plays an important role. However, there are some fundamental problems in the analysis of accidents and in the definition of human error. The human adaptability and learning ability are the subjects that should be examined in particular when it comes to analyzing the concept of human error. All these expressions show that errors cannot be considered separately from the system in modern working environments. This is an undeniable effect on the faults in gas turbine systems.

Doel. (1990) investigated the condition monitoring of gas turbine engines and developed software algorithms for the interpretation of the limited available sensors [4]. Bea (1994) summarized the impacts of human errors in marine and non-marine structures[5]. Dearden and Harrison (1996, June) examined the relationship between operator actions and system hazards and presented a simple case study about the human-machine interface (HMI) [6]. DePold and Gass (1998, June) presented maintenance strategies for gas turbine engine generators and used artificial neural network filters to improve data quality[7]. Brotherton et al. (2000) evaluated the critical component faults in gas turbine engines and developed a new technique by the help of data collected from operating engines[8]. Latorella and Prabhu (2000) mentioned the productivity and efficiency of airline operations and evaluated the human error in aviation maintenance and inspection [9]. Rothblum(2000) studied the causes of human error in the maritime industry [10]. Ganguli (2002) developed a Fuzzy logic intelligent system for gas turbine fault isolation [11]. Li (2002) proposed the performance analysis based method for gas turbine fault diagnosis [12]. Mosleh and Chang (2004) evaluated operator response in probabilistic safety assessments (PSA) of nuclear power plants and proposed the conventional method for human reliability analysis (HRA) [13]. Konstandinidou et al. (2006) used a fuzzy classification system for human reliability analysis and proposed cognitive reliability and error analysis method (CREAM) for maintenance tasks in control room operations [14]. Dhillon and Liu (2006) analyzed and reviewed the human error in maintenance systematically [15].Kim et al. (2011) examined the human error probabilities related marine accidents using an analysis method [16]. Yang et al. (2013) determined the human reliability performance using a modified CREAM[17]. Noroozi et al. (2014) analysed the human factors in pre- and post-maintenance operations. They used a pump as the test example and calculated the human error probability (HEP) [18]. Islam et al. (2016) calculated the human error probabilities for 43 different activities of marine engines [19]. Islam et al. (2018) evaluated the maintenance operations on board ships and developed human error probability model for seafarers[1].

In the view of mentioned studies, although there has been a wide variety of evaluations to assess human error, human error probabilities on faults in gas turbine systems using the Cream method have not been evaluated. In order to correct this gap, this article aims to determine the possibility of human error in certain faults in gas turbine operations in the maritime industry.

3. CREAM Methodology

A robust methodology allowing the prediction of human error probability and the analysis of cognitive human reliability, Hollnagel (1998) introduced CREAM method, which is suited to perform retrospective and prospective examination [20]. This method identifies parts of the work, tasks or actions requiring or dependent upon human recognition and therefore, open to the effect of variations in cognitive reliability. Some researchers (e.g. Akyuz, 2015) attempted to draw fine distinctions between basic and extended versions of the CREAM in which a comprehensive human error assessment is made [21]. The basic one focuses on initial screening of human interactions, the extended one a far-reaching analysis for human interaction by adopting outputs of the basic version.

For the determination of the probability of human error in numerous actions, the CREAM is comprised of four different control modes. It is a derivation of COCOM (Contextual Control Model) addressing the practical and conceptual basis for the improvement of human performance[21-22]. The models are scrambled, opportunistic, tactical and strategic. Due to the strategic mode introducing the lowest probability of human error, the highest human error probability is alluded by the scrambled control mode. Table 1 below illustrates control modes and relevant failure probabilities. With the aim of quantifying the probability of human error, the CREAM embraces a few main steps.

Table 1. *Control Modes and HEP Intervals*

Control Mode	HEP Interval
Strategic	0.5 E-5 < P < 1.0 E-2
Tactical	1.0 E-3 < P < 1.0 E-1
Opportunistic	1.0 E-2 < P < 0.5 E-0
Scrambled	1.0 E-1 < P < 1.0 E-0

3.1. Introducing Control Modes

Based on COCOM, the theoretical background of CREAM with four control modes, as explained above, is scrambled, opportunistic, tactical and strategic. Experiences of personnel and knowledge of dependency are influential in the control modes. Control modes and effects are shortly given: [23].

Scrambled control mode: The operator's exerting minimum control over the system is indicated by scrambled modes because of the randomness or unpredictability of the choice of next action.

Opportunistic control mode: Careless characteristics of the situation stemming from lack of time, inexperienced operator, etc. determine the choice of next action.

Tactical control mode: Performance of operator nearly follows planned procedures; albeit, still the possibility of some deviation.

Strategic control mode: In addition to the time available, operator conceivably thinks action at a higher level. This mode enables more efficient action than the others to be conducted by the operator.

For initial screening of human failure events to be monitored, Figure 1 is usable and defines the basic operator control modes[23].

3.2. Assess Common Performance Conditions (CPCs)

Definition and assessment of CPC are required in this method to find out cognition and human context. The CPC state the conditions of the operator such as a performance shaping factors which are excessively influential on the human error. CPCs level and relevant performance effect are illustrated in Table 2 [20].

So as to predict the probability of human error, the CPC score is required. In the calculation of the CPC score, the number of times, which gives rise to decrease performance reliability or increase performance reliability, is considered. Subsequent to the accumulation of CPC scores, the control modes are established to determine human error probability interval. The combined CPC scores, ∑reduced and ∑improved signify the appropriate control mode providing the probability of human failure intervals. Conversely, CPC ∑ not significant does not affect the HEP [21].

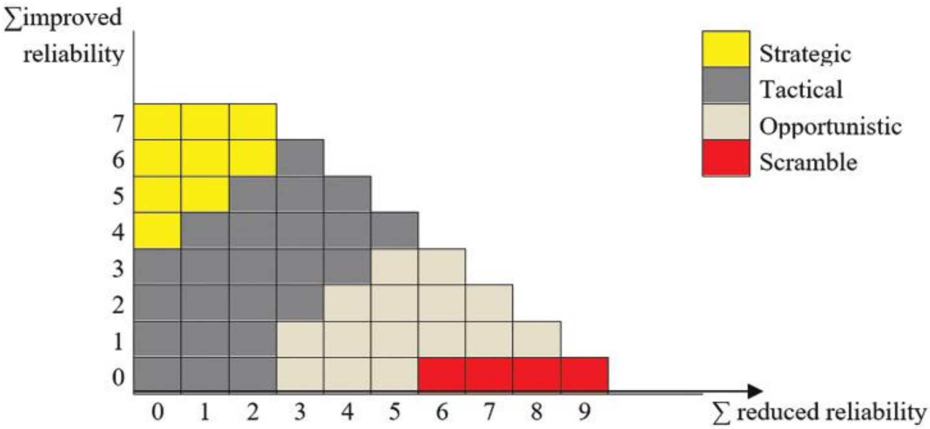


Figure 1. *Operator Control Modes*

Table 2. *CPC Level and Performance Effect*

CPC	CPC level/description	Effects
Adequacy of organisation	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Reduced
	Deficient	Reduced
Working conditions	Advantageous	Improved
	Compatible	Not significant
	Incompatible	Reduced
Adequacy of MMI and operational support	Supportive	Improved
	Adequate	Not significant
	Tolerable	Not significant
	Inappropriate	Reduced
Availability of procedures/plans	Appropriate	Improved
	Acceptable	Not significant
	Inappropriate	Reduced
Number of simultaneous goals	Fewer than capacity	Not significant
	Matching current capacity	Not significant
	More than capacity	Reduced
Available time	Adequate	Improved
	Temporarily inadequate	Not significant
	Continuously inadequate	Reduced
Time of day	Day-time (adjusted)	Not significant
	Night-time (unadjusted)	Reduced
Adequacy of training and experience	Adequate, high experience	Improved
	Adequate, limited experience	Not significant
	Inadequate	Reduced
Crew collaboration quality	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Not significant
	Deficient	Reduced

3.3. Identifying context influence index (CII)

By dint of CII in the CREAM, quantification of human error is ensured. Herein, the CPCs are likely to be quantified. The deduction of the number of reduced CPCs from improved CPCs ascertains this value. An equation (1) demonstrates the quantification process of CII. In the equation, X provides the number of reduced CPCs and Y indicates the number of improved CPCs [21-24].

$$CII = X - Y = \sum reduced - \sum improved \quad (1)$$

He et al. (2008) describe a specific control mode capable of converting CII into a crisp value in line with the CPCs score [24]. Table 3 displays specific control modes and CII values in which the control modes are classified [23-24]. In the control modes, as ∑not significant combined CPCs scores have no significant effect over the HEP value, the CII value is considered 0.

Table 3. *Specific Control Modes and CII Values*

Control mode	CII values
Strategic	-7 to -3
Tactical	-3 to 1
Opportunistic	2 to 5
Scrambled	6 to 9

3.4. Predicting Performance Influence Index (PII)

Akyuz (2015) argues the PII values were introduced with the aim of specifying the actual weighting factors for cognitive functions such as planning, executing, observation and interpretation [21]. Each CPC possesses a different PII value and each one of them is a different weighting factor from others. This calculation serves to monitor screening stage. Equation (2), within this scope, shows CII value in relation to PII. In the equation, the PII value basis of the weighting factor is introduced in CREAM extended version and arranged by expert judgement [21-24].

$$CII = \sum_{i=1}^{9} PII \quad (2)$$

3.5. Calculating Cognitive Failure Probability (CFP)

In this step, cognitive human failure probability is decided, for human failure probability for each cognitive failure type is defined by CFP. The nominal cognitive failure probability (CFP0) is designated for each operational task. The CFP0 acquires a set of sources and provides the nominal value given for failures of cognitive function [20-21]. In CREAM, under four cognitive functions are introduced thirteen generic failure types. Table 4 [23-24] illustrates nominal cognitive failure probability.

According to Akyuz (2015), He et al. (2008), Apostolakis et al. (1988) the following equation (3) identifies the correlation between the CII and CFP [21-24-25]. The logarithmic equation is employed to depict changes in human error interactions with the variance in external conditions.

$$\log\left(\frac{CFP}{CFP_0}\right) = k.CII \quad (3)$$

In the equation, k explains a constant

Table 4. *Nominal Cognitive Failure Probability*

Cognitive Function	Generic Failure Type	Basic Value
Observation	O1. Wrong object observed	1.0E-3
	O2. Wrong identification	7.0E-2
	O3. Observation not made	7.0E-2
Interpretation	I1. Failurey diagnosis	2.0E-1
	I2. Decision error	1.0E-2
	I3. Delayed interpretation	1.0E-2
Planning	P1.Priority error	1.0E-2
	P2.Inadequate plan	1.0E-2
Execution	E1. Action of wrong type	3.0E-3
	E2. Action at wrong time	3.0E-3
	E3. Action on wrong object	5.0E-4
	E4. Action out of sequence	3.0E-3
	E5. Missed action	3.0E-2

coefficient and determined by following equations (4), (5), (6) and (7) [24].

$$\log(\mathrm{CFP}_{\max} / \mathrm{CFP}_0) = k.CII_{max}, \quad (4)$$

$$\log(\mathrm{CFP}_{\min} / \mathrm{CFP}_0) = k.CII_{min}, \quad (5)$$

$$k = \log(\mathrm{CFP}_{\max}/\mathrm{CFP}_{\min})/(\mathrm{CII}_{\max} - \mathrm{CII}_{\min}) \quad (6)$$

$$\mathrm{CFP}_0 = \mathrm{CFP}_{\max}/10^{k.\mathrm{CII}_{\max}} \quad (7)$$

Akyuz (2015) points out, k is found 0.26 by considering CFPmax as 1.0000 and CFPmin as 0.00005 [21]. In the light of findings, equation (8) is utilized to calculate adjusted CFP which also specifies HEP.

$$CFP = CFP_0 \; x \; 10^{0.26.CII} \quad (8)$$

4. Application

4.1. Operation of Gas Turbine Components in Ship

Gas turbines have been used to propel ships for many years, all nations have evaluated this technology in war ships and commercial fleets. A gas turbine engine is referred to as an internal combustion engine that utilizes gas as a working fluid to rotate the turbine. This engine comprises a compressor, a combustor, a turbine, output shaft & gearbox, and an exhaust. In gas turbine technology, the air-fuel mixture is ignited after hot gas turns turbine blades so that the turbine drive shaft rotates. Generator power is provided with the return of the turbine. As a result, the generator magnet moves electrons and electricity is generated at this point [8-11].

Gas turbines are complex systems and many faults can occur in different parts of them. Hydraulic-Pneumatic Equipment, Electronic Control Equipment and Bearing Equipment are important parts of gas turbines. There are many points to be checked by the seafarers regarding this equipment. Especially, fuel and pressure regulator filter, oiling pressure, valve pressure and temperature value for related equipment must be checked by seafarers considering the values determined by the manufacturers for the equipment.

The maintenance person plays an important role in equipment reliability and management. It is known that human error often occurs during the maintenance phase. So critical values of the relevant equipment must be checked in time so that no failure occurs in the gas turbine components.

4.2. Problem Description

In the management of gas turbine technology, it is known that serious damage caused by human error occurs and capital investment is lost in a significant amount. Many faults occur on the gas turbine components due to human influence. The faults in the gas turbine components are described as in Table 5 [26-27].

These faults and possible effects in the gas turbine components are shown as in Table 5. When the causes of these faults are examined, the importance of human effect is great. Because all the components are operated with the values given by the manufacturer and these controls are made with human influence.

4.3. Analysis of Respondents

It is important to get the views of experts in the field of inadequate information access in the maritime industry. Three expert opinions were received in this study. One of them is a professor in the department of marine engineering operations and has been working as a teaching member for more than 10 years. The other one is the third engineer on the ships and also the manager of a maritime company and has 6 years working experience. Lastly, he is as a naval architecture and

Table 5. *Possible Operational Gas Turbine Faults*

No	Potential faults	
1.	Variations in rpm signal	
	F1.	Electronic speed regulator failure
	F2.	Starter motor coupling failure
	F3.	Connecting shaft has been broken between turbine and gear box
2.	Falling and fluctuations in pressure value	
	F4.	Sufficient pressure fuel does not come for fuel pump
	F5.	The oil pressure switch failure
	F6.	The fuel solenoid valve failure
3.	Insufficient compressed air flow	
	F7.	Blocked the outlet of air pressure regulator
	F8.	Load control valve failure
	F9.	Pressure regulator filter clogged
4.	Excessive change in exhaust gas temperature	
	F10.	Temperature control unit failure
	F11.	Problems in automatic control air supply lines
	F12.	Fuel atomiser filter clogged
5.	Turbine Vibrations	
	F13.	Eccentricity of shafts
	F14.	Low oiling pressure

marine engineer and has worked as a maintenance engineer for shipyards for 6 years. The causes and defects of gas turbine faults were evaluated by these 3 experts. The answers given by the experts were evaluated using the CREAM method and realistic results were obtained.

4.4. Extensive Human Error Prediction for Operation Procedure of Gas Turbine Components

Table 5 provides the significant gas turbine faults (F) stemmed from human error during operation. The potential operational faults arising from human errors are evaluated through brainstorming of three experts.

Prior to determining the CPC, working environment of the gas turbine, time of day, engine crew collaboration, noise level, engine crew ability, and fatigue level are assessed by the marine experts. Table 6 presents the descriptor of the CPCs evaluation by the consensus of marine experts.

Thus, the CPC effects through engine crew performance reliability are available related to Table 2. In this regard, the equation (1) is utilized to quantify. The CII value, here, can be found as CII = -1 for No.1 (high heat level in all exhaust cylinders of the engine) No.1, CII = -2 for No.2, CII = 0 for No.3, CII= 2 for no.4, CII=2 for No.5 and CII= -2 for No.6 in diesel engine operational faults owing to human error. In consideration of the findings, the PII values of the CPCs are described in Table 7. The quantification process of CII value in the extended version of CREAM is presented applying equation (2) and same provided in Table 8 as well [20].

Table 6. *CPCs Evaluation by the Consensus of Experts*

CPCs and performance reliability					
CPC	Falling and Fluctuations in Pressure Value	Variations in rpm signal	Insufficient compressed air flow	Excessive change in exhaust gas temperature	Turbine Vibrations
Adequacy of organisation	Very Efficient	Efficient	Very Efficient	Efficient	Efficient
Working conditions	Compatible	Advantageous	Advantageous	Compatible	Incompatible
Adequacy of MMI and operational support	Tolerable	Supportive	Tolerable	Supportive	Supportive
Availability of procedures/ plans	Appropriate	Acceptable	Acceptable	Inappropriate	Acceptable
Number of simultaneous goals	Matching current capacity	More than capacity	Matching current capacity	Fewer than capacity	More than capacity
Available time	Temporarily inadequate	Adequate	Temporarily inadequate	Temporary inadequate	Adequate
Time of day	Day-time	Day-time	Night-time	Night-time	Day-time
Adequacy of training and experience	Adequate limited experience	Adequate high experience	Adequate limited experience	Adequate high experince	Adequate high experience
Crew collaboration quality	Efficient	Very Efficient	Efficient	Deficient	Very Efficient

Table 7. *PII for CPCs (cont')*

CPC	CPC Level	PII
Adequacy of organisation	Very efficient	- 0.6
	Efficient	0
	Inefficient	0.6
	Deficient	1.0
Working conditions	Advantageous	- 0.6
	Compatible	0
	Incompatible	1.0
Adequacy of MMI and operational support	Supportive	- 1.2
	Adequate	- 0.4
	Tolerable	0
	Inappropriate	1.4
Availability of procedures/ plans	Appropriate	- 1.2
	Acceptable	0
	Inappropriate	1.4

./..

Table 7. *PII for CPCs (cont')*

CPC	CPC Level	PII
Number of simultaneous goals	Fewer than capacity	0
	Matching current capacity	0
	More than capacity	1.2
Available time	Adequate	- 1.4
	Temporarily inadequate	1.0
	Continuously inadequate	2.4
Time of day	Day-time (adjusted)	0
	Night-time (unadjusted)	0.6
Adequacy of training and	Adequate, high experience	- 1.4

Following the calculation of CII values for each main failure type, the CFP values are established to analyse gas turbine operational faults in conjunction with human factor. The equation (7) is implemented to calculate CFP. In Table 8 the adjusted CFP values are illustrated along with cognitive activity, cognitive function and generic failure type.

4.5. Findings and Discussion

Gas turbine systems consist of a very complex structure and are known to be a maintenance and repair operation for each equipment. As a consequence of this situation, problems can arise in the gas turbine components due to intense work, inexperience or technical insufficiency. For this reason, technical personnel have critical tasks.

In this study, human error probabilities in gas turbine faults were shaped by the answers given by the experts mentioned above and numerically expressed by the Cream method. The operational faults described in table 5 above and the hazards

Table 8. *Adjusted CFP Values*

No	Failure	Cognitive activity	Cognitive function	Generic failure type	Adjusted CFP
1	F1.	Observe	Observation	O3	4,3E-02
	F2.	Execute	Execution	E3	3,1E-04
	F3.	Diagnose	Interpretation	I2	6,2E-03
2	F4.	Co-ordinate	Planning	P2	5,6E-04
	F5.	Observe	Observation	O1	5,6E-05
	F6.	Plan	Planning	P2	5,6E-04
3	F7.	Monitor	Observation	O3	8,9E-02
	F8.	Evaluate	Interpretation	I1	2,5E-01
	F9.	Co-ordinate	Planning	P2	1,3E-02
4	F10.	Monitor	Observation	O3	8,9E-02
	F11.	Record	Execution	E2	3,8E-03
	F12.	Compare	Interpretation	I1	2,5E-01
5	F13.	Identify	Interpretation	I3	1,5E-03
	F14.	Compare	Interpretation	I3	1,5E-03

that may occur due to these faults are expressed. The CFP values determined for the 14 critical faults for which human error probabilities are expressed for these operations are shown in Table 8. As a result of the answers of the experts, the CFP values range from 5,6E-05 to 2,5E-01. According to this result, Load control valve failure (F8; CFP Value: 2,5E-01), Fuel atomiser filter clogged (F12; CFP Value: 2,5E-01) calculated as the most effective criteria based on the human error. Valves and filters are known as the critical elements in terms of gas turbines. The filters have to be cleaned in time, and the maintenance of the valves must be done periodically. At this point, the importance of human impact is greater.

According to the results obtained in Table 8, Starter motor coupling failure (F2; CFP Value: 3,1E-04 and the oil pressure switch failure (F5; CFP Value: 5,6E-05) are defined as faults where the human effect is the fewest. This result is due to the fact that these faults are caused by mechanical problems rather than human influences.

These results, obtained through expert opinions and the CREAM method, represent the probability of human error in gas turbine faults. To minimize all these possibilities, the relevant personnel must follow operational procedures, take security precautions and control the flow of information.

5. Conclusion

Gas turbine systems are used in different areas of the industry. These systems have a low weight / power ratio compared to other engines. Because of this feature, it is also preferred in maritime. It is known that these systems consist of very complex components. In order to provide safe navigation in maritime, operational activities must be done meticulously in the ships where these systems are used. These operations are carried out on human control and minor negligence leads to major problems. In this study, 14 faults in the gas turbine components and the hazards that may occur due to this are stated. The human error probabilities that may cause these faults are calculated using the Cream method in the light of expert opinions. According to the results obtained, the technical personnel to be assigned by the shipowners must be more equipped and careful to prevent faults of high probability of human error. For further studies, the author aims to improve the methodology for assessing human errors on faults in gas turbine operations on board the ship.

References

[1] Islam, R., Khan, F., Abbassi, R., & Garaniya, V. (2018). Human error probability assessment during maintenance activities of marine systems. Safety and health at work, 9(1), 42-52.

[2] De Felice, F., & Petrillo, A. (2018). An Overview on Human Error Analysis and Reliability Assessment. In Human Factors and Reliability Engineering for Safety and Security in Critical Infrastructures (pp. 19-41). Springer, Cham.

[3] Sirignano, W. A., & Liu, F. (1999). Performance increases for gas-turbine engines through combustion inside the turbine. Journal of propulsion and power, 15(1), 111-118.

[4] Doel, D. L. (1990, June). The role for expert systems in commercial gas turbine engine monitoring. In ASME 1990 International Gas Turbine and Aeroengine Congress and Exposition (pp. V005T15A014-V005T15A014). American Society of Mechanical Engineers.

[5] Bea, R. G. (1994). The Role of Human Error in Design, Construction, and Reliability of Marine Structures (No. SR-1353). CALIFORNIA UNIV BERKELEY DEPT OF CIVIL ENGINEERING.

[6] Dearden, A. M., & Harrison, M. D. (1996, June). Impact and the design of the human-machine interface. In Computer Assurance, 1996. COMPASS'96, Systems Integrity. Software Safety. Process Security. Proceedings of the Eleventh Annual Conference on (pp. 161-170). IEEE.

[7] DePold, H. R., & Gass, F. D. (1998, June). The application of expert systems and neural networks to gas turbine prognostics and diagnostics. In ASME 1998 International Gas Turbine and Aeroengine Congress and Exhibition (pp. V005T15A009-V005T15A009). American Society of Mechanical Engineers.

[8] Brotherton, T., Jahns, G., Jacobs, J., & Wroblewski, D. (2000). Prognosis of faults in gas turbine engines. In Aerospace Conference Proceedings, 2000 IEEE (Vol. 6, pp. 163-171). IEEE.

[9] Latorella, K. A., & Prabhu, P. V. (2000). A review of human error in aviation maintenance and inspection. International Journal of Industrial Ergonomics, 26(2), 133-161.

[10] Rothblum, A. M. (2000, October). Human error and marine safety. In National Safety Council Congress and Expo, Orlando, FL (p. 7).

[11] Ganguli, R. (2002). Fuzzy logic intelligent system for gas turbine module and system fault isolation. Journal of propulsion and power, 18(2), 440-447.

[12] Li, Y. G. (2002). Performance-analysis-based gas turbine diagnostics: A review. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 216(5), 363-377.

[13] Mosleh, A., & Chang, Y. H. (2004). Model-based human reliability analysis: prospects and requirements. Reliability Engineering & System Safety, 83(2), 241-253.

[14] Konstandinidou, M., Nivolianitou, Z., Kiranoudis, C., & Markatos, N. (2006). A fuzzy modeling application of CREAM methodology for human reliability analysis. Reliability Engineering & System Safety, 91(6), 706-716.

[15] Dhillon, B. S., & Liu, Y. (2006). Human error in maintenance: a review. Journal of quality in maintenance engineering, 12(1), 21-36.

[16] Kim, H. T., Na, S., & Ha, W. H. (2011). A case study of marine accident investigation and analysis with focus on human error. Journal of the Ergonomics Society of Korea, 30(1), 137-150.

[17] Yang, Z. L., Bonsall, S., Wall, A., Wang, J., & Usman, M. (2013). A modified CREAM to human reliability quantification in marine engineering. Ocean Engineering, 58, 293-303.

[18] Noroozi, A., Khan, F., MacKinnon, S., Amyotte, P., & Deacon, T. (2014). Determination of human error probabilities in maintenance procedures of a pump. Process Safety and Environmental Protection, 92(2), 131-141.

[19] Islam, R., Abbassi, R., Garaniya, V., & Khan, F. I. (2016). Determination of human error probabilities for the maintenance operations of marine engines. Journal of Ship Production and Design, 32(4), 226-234.

[20] Hollnagel, E., (1998). Cognitive reliability and error analysis method. Amsterdam: Elsevier.

[21] Akyuz, E. (2015). Quantification of human error probability towards the gas inerting process on-board crude oil tankers. Safety Science 80: 77-86

[22] Hollnagel, E., (1993). Human reliability analysis: Context and control. London, UK: Academic Press.

[23] Akyuz, E. and Celik, M. (2015). Application of CREAM human reliability model to cargo loading process of LPG tankers. Journal of Loss Prevention in the Process Industries 34: 39 – 48.

[24] He, X., Wang, Y., Shen, Z., Huang, X., (2008). A simplified CREAM prospective quantification process and its application. Reliability Engineering and System Safety 93: 298–306.

[25] Apostolakis, G.E., Bier, V.M., Mosleh, A. (1988). A critique of recent models for human error rate assessment. Reliability Engineering and System Safety,22: 201 - 217.

[26] Balin, A., Demirel, H., & Alarcin, F. (2016). A novel hybrid MCDM model based on fuzzy AHP and fuzzy TOPSIS for the most affected gas turbine component selection by the failures. Journal of Marine Engineering & Technology, 15(2), 69-78.

[27] Balin, A., Demirel, H., & Alarçin, F. (2016). An Evaluation Approach For Eliminating The Failure Effect In Gas Turbine Using Fuzzy Multiple Criteria. International Journal of Maritime Engineering, 158, A219-A230.

This Page Intentionally Left Blank

Received: 16 January 2019 *Accepted: 10 April 2019* *DOI ID: 10.5505/jems.2019.18189*

Journal of ETA Maritime Science

JEMS JOURNAL

Corresponding Author: Özlem SANRI

Social Media Usage Patterns of Turkish Maritime Businesses: A study on Facebook

Fatma Özge BARUÖNÜ, Özlem SANRI

Doğus University, Department of International Trade and Business, Turkey
olatif@dogus.edu.tr; ORCID ID: https://orcid.org/0000-0001-5533-775X
osanri@dogus.edu.tr; ORCID ID: https://orcid.org/0000-0002-9788-6594

Abstract

Social media has been widely used by businesses nowadays. Although in B2B industry, social media marketing isn't grown up as fast as it was in B2C market, many businesses begun to develop social media strategies and reach to new and existing corporate customers via social media recently. In this study, the main purpose is to examine social media usage patterns of Turkish maritime transportation companies through Facebook. In order to identify the social media usage habits of Turkish maritime transportation companies an exploratory study was conducted. In the period between January-November 2018, the maritime companies existing in Facebook are analyzed with a content analysis in terms of contents of the posts and stakeholder engagement levels. The findings show that posts on corporate image and special days are highly re-shared and taken positive reactions by followers. At the end of the study, suggestions for practitioners and direction for further studies are presented.

Keywords: *Maritime Business, Facebook, Social Media, Engagement, Stakeholder Approach.*

Denizcilik İşletmelerinde Sosyal Medya Kullanım Modelleri: Facebook Üzerine Bir Çalışma

Öz

Günümüzde işletmeler tarafından sosyal medya yoğun olarak kullanılmaktadır. Her ne kadar B2B pazarında sosyal medya pazarlaması B2C pazarına göre daha hızlı büyümese de, çoğu işletme son günlerde sosyal medya stratejilerini geliştirmeye ve yeni ve mevcut kurumsal müşterilerine sosyal medya ile ulaşmaya başlamıştır. Bu çalışma Türkiye'de yer alan denizcilik işletmelerinin sosyal medya kullanım şekillerini Facebook üzerinden incelemeyi amaçlamıştır. Türk deniz taşımacılığı şirketlerinin sosyal medya kullanım alışkanlıklarını belirlemek amacıyla keşifsel bir araştırma yapılmıştır. Ocak-Kasım 2018 dönemleri içerisinde Facebook hesabı olan denizcilik işletmeleri, gönderilerinin içerikleri ve paydaş katılımı seviyeleri açısından içerik analizi yöntemi ile analiz edilmiştir. Bulgular, kurumsal imaj ve özel günler gönderilerinin yüksek oranda yeniden paylaşıldığını ve takipçiler tarafından bu gönderilere olumlu tepkiler verildiğini göstermektedir. Çalışmanın sonucunda, uzmanlara yönelik önerilere ve ileriki çalışmalar için yönlendirmelere yer verilmiştir.

Anahtar Kelimeler: *Denizcilik İşletmeleri, Facebook, Sosyal Medya Etkileşimi, Paydaş Yaklaşımı.*

To cite this article: Baruonu, F. O. & Sanrı, Ö. (2019). Social Media Usage Patterns of Turkish Maritime Businesses: A study on Facebook. *Journal of ETA Maritime Science*, 7(2), 165-177.
To link to this article: https://dx.doi.org/10.5505/jems.2019.18189

1. Introduction

In B2B marketing, the companies are operating in a highly competitive environment though marketing communication tools have critical importance [1]. In order to create and share rich, interactive, fast and customized contents, the professionals in B2B market have benefit social media with the rising of Web 2.0. [2]. Today social media has become one of the most important parts of any digital marketing strategy [3]. Mangold and Faulds [4] offered social media as a hybrid component of the promotional mix and as an integral part of the businesses' integrated marketing communications strategy. For a sustainable profit having a web site is not adequate thus companies are now focused to achieve relational exchanges with their customers therefore social media is the key for B2B companies to be closer to their potential and existing customers.

Shipping in a highly competitive environment is an international industry by nature. Nearly more than 85% of world's international trade is carried by maritime transportation. Global seaborne trade in 2017 has been reached to 10,7 billion tons with a %4 annual growth which can be explained as the fastest growth in five years [5]. Thus, shipping companies' services are produced to satisfy the derived demand for the transport of cargoes. Maritime transportation firms are serving to other businesses and their main focus is to cut their costs while satisfying their customers. When doing this, they are neglecting to allocate their financial resources for marketing campaigns or advertisements in order to improve their brand images and brand values [6]. However, the benefits of marketing efforts, in particular utilizing social media is quite important for many B2B companies to enhance their brand awareness and brand image.

The aim of the study is enhancing our understanding on social media usage of maritime transportation companies which are one of the biggest players of B2B service industry. In B2C market social media and its benefits for businesses has taken too much attention by far, however role of social media in B2B market is quite new and fruitful research area. Recent researches put attention to investigate the social media usage in maritime industry newly. However, this research will be the first for identifying Turkish maritime transportation companies' Facebook usage by adopting stakeholder engagement index which will be a contribution for Turkish maritime transportation practitioners to improve their social media pages.

The rest of the paper is organized as follows. A literature review on social media usage habits in maritime shipping industry was employed. Then an exploratory research was conducted to understand the social media usage patterns of Turkish maritime transportation companies through content analysis technique. Stakeholders engagement matrix which was developed by Bonson and Ratkai (2013) was used to measure popularity, commitment and virality of maritime transportation companies' Facebook accounts. Finally, suggestions to increase the power and collaborative functions of social media platforms, theoretical and managerial implications were discussed in conclusion part.

2. Social Media

Social media has enabled the communication as many-to-many [7]. which means that audience in social media interacts both with the companies and customers [4]. Therefore, while planning communication in social media, it is important to reshape of communication by identifying how messages are created, composed, disseminated and consumed [8] and producing contents which have high potential to have been reed and shared by the followers.

The general perception of B2B marketers was that social media wouldn't serve potential to B2B companies, even it is an irrelevant platform to connect their customers [9]. Due to the nature of B2B companies, marketers think that purchasing process requires face-to-face interaction [10]. One of the reason behind this thought is the lack of understanding how to do so, and perceived benefits [11]. Over time, this opinion was left and B2B companies try to have an existence in social platforms to be more visible. Although these companies don't expect to take order through social media, they remark that they can benefit from the advantages of social platforms. North Venture Partners [12] distinguish the areas where B2B companies could use social media effectively: public relations, customer service, market research, brand marketing, promotion, consumer education, sales, product expansion, and customer relationship management. The main aim is to "get closer to the customers", while getting the attention of press, gaining higher employee engagement and developing more brand awareness. Users and followers of B2B social media include employees of companies, customers, industry experts, and business partners or suppliers. According to Forrester Research, such people use social media platforms for both consumption of information/ news and interaction [13].

On the other hand, in the literature the academics has directed their research on B2C companies' social media marketing efforts and strategies and has provided results regarding positive and negative returns to companies by far [14]. Researchers began to put attention to understand social media communication for B2B business only for a couple of years. Walters [15] argued that B2B organisations can also benefit from social media they are able to follow three strategies which are; information rich strategy, relational exchange and joint learning. Balmer and Low [16] and Brennan and Croft [17] explored the issue from branding side, Mehmet and Clarke [18] analysed social media semantics for B2B. Jarvinen et al [9] and Michaelidou et al. [11] studied on social media metrics for industrial firms. Siamagka et al. [19] defined the factors affecting the adoption of social media in B2B organisations. Andersson and Wikström [20] investigated why and how B2B companies use social media. In their research they found out that B2B companies increased their customer relationship, strengthened the brand and support sales by using social media.

Frequently-used social media platforms can be listed as Facebook, LinkedIn, Twitter, YouTube, and Instagram [21]. Companies and customers interact with different B2B social media platforms in different ways [20]. Facebook is the oldest and most popular platform among the all social media tools therefore it has the most members compared with others. There are successful marketing practices in terms of usage of Facebook accounts.

3. Marketing and Stakeholder Approach

To understand social media usage in B2B context, stakeholder theory was frequently benefitted from. Stakeholder view defines organisations as a grouping of stakeholders and stresses the importance of managing different stakeholders' interest [22]. For maritime transportation companies in order to successfully manage the relationships with the stakeholders it is vital to know how to communicate with them that includes customers, employees, shareholders, regulators and investors [20].

Bruce and Shelly [23] define stakeholder engagement as the interaction among the individuals and groups who involve in a corporation. From the external customer perspective, social media provide product and process info, enhance brand image and corporate image, deliver advertisements, help to improve customer relationship management and after sales services. From the internal customer perspective, it can be used for announcing the vacant positions, honour the staff and strength the internal relations. From the community perspective, company can share special messages and announce social responsibility campaigns.

There are different ways of measuring social media efficiency. One of them has three parts; volume – how many people talk, influence – who talks, and sentiment – what people talk. Number of friends on company's profile, number of likes, number of comments and shares are the frequently used scales to measure the success of a social media tool. Also, tone of users comments (positive, neutral, negative) show the reflections of the customers [24]. Maersk Line's managers measured engagement on Facebook by a formula where they take a sample of their latest 10 posts, added up the likes, number of comments and shares. This total value is compared to other values that other multinational brands have. On the other hand, measuring the direct effects of social media on B2B companies is very tough [11, 25].

With the aim of creating brand awareness and positive attitude to their company maritime transportation companies begin to apply communication strategies through social media. As Facebook is the oldest social media platform and number of users exceed millions, maritime transportation companies first open a page with their brand name. Maersk Line is a good example that use the photos of its ships by combining them with interesting stories. Even they posted a photo with a giraffe on a container ship and took the attention of their fans. In this process the employees also help the company by sharing these posts. Today Maersk Line reach to over 2 million funs in Facebook [13]. In general, Facebook gives opportunities to users to connect with their followers in a visual and conversational structure.

Over time, companies spread to other media like Twitter, Instagram and LinkedIn and also they keep to post in Facebook at the same time. Twitter posts are mostly a mix of more serious news than the Facebook page (retweets from employees, photos, and announcement). Twitter audience include the trade press, shipping professionals, customers, and employees and the Twitter user is 10 times more influential than an average Facebook user [13]. LinkedIn is the most corporate platform and the tone of voice was "more corporate. The LinkedIn page also had several tabs, and enable to listen customers and discuss with them. Instagram is known with the facility of publishing high quality photos and filter effects. Indeed, it is more than it. Hashtags let the companies to create topics and inspire the people taking photos about their business process and share them with their own network.

All these platforms not only increase the brand awareness and provide visibility but also they serve as customer service. Many fans and followers voluntarily defence the firm when they saw a negative comment on the page before the official customer services take action [25]. According to Gorry and Westbrook [25] some companies have already integrated feedback into their organisational processes.

In terms of measuring the stakeholder engagement, in the literature, stakeholder engagement metrics were used to analyze social media usage of several sectors including university libraries, tourism, municipilaties, sports organizations (football and basketball teams), companies which are listed in Carbon Disclosure Project, third-party logistics companies, women entrepreneurs, banks, public transportation agencies, political parties, fashion retailers, telecommunications sector and museums. The populations searched in the previous studies were generally belong to B2C arena which shows the lack of researches in business to business sectors.

Manetti et al. (2016) analyzed stakeholder engagement in Canadian and American public transportation agencies. They applied stakeholder engagement metrics to 33 transportation agencies. Their results show that public transportation agencies use social media in order to present their activities to public. Facebook is the most popular platform for interaction with stakeholders, on the other hand Twitter usage is mostly focused on contents about public information [26]. In B2B sector Sürücü and Şakar (2018) examined the relationship of Turkish logistics service providers with their stakeholders by stakeholder engagement metrics. The findings show that Turkish logistics service providers utilize Facebook as a communication and engagement channel [27]. Metushi and Fradeani (2019) analyzed 200 Albanian companies social media reporting practices by focusing on contents shared by the companies on their Facebook, Twitter and Linkedin pages. The findings reveal that Facebook is the most preferred social media platform. The main focus for using social media is marketing activities [28]. As there is scant research in adopting social media engagement in maritime context it is aimed to understand usage habits of Facebook by maritime transportation companies.

4. Methodology

An exploratory study was conducted to understand the social media usage habits of maritime shipping firms in Turkey. Therefore, a content analysis was employed by investigating the social media accounts of all maritime transportation companies in Turkey. Content analysis is a widely used qualitative research technique [29]. As methodology, stakeholder engagement metric is applied which is developed by Bonson and Ratkai (2013) to calculate the index values [30]. This metrics which could be obtained through the publicly available data are shown in Table 1.

The following steps has been taken to identify these companies; first a full list of maritime transportation companies were provided from UTIKAD (Association of International Forwarding and Logistics Service Providers) (September,2018). Although there are 458 members, the list is limited only with maritime transportation companies. Airway, railway, road transportation companies are eliminated. Thus, the population consists of 160 companies. Sampling method of the study is purposeful sampling because, only the companies posted more than 5 posts in their page by far are included to the sample. Therefore sample size is defined as 15. Next, posts are classified in 4 categories depending on their subject by authors. Main topics were determined as, a) special days/events/occasions, b) corporate image, c)sectoral news and d) announcements. For each company, the contents of all the Facebook posts are examined by two researchers who made their own judgements for classification of the contents. To enable inter-coder reliability, Cohen's Kappa value was calculated and found to be varied between 0,90-1,00 which is exceed the threshold (0,75).

For each category engagement statistics (number of followers, likes, comments and shares) were reported. Number of followers and number of likes are counted for all times whereas likes and shares are only accounted for the period of January-September 2018. Comments of followers (if available) are also analysed and categorised. (1) popularity; (2) commitment; and (3) virality were used to measure stakeholder engagement [30]. Popularity is related to the number of likes whereas commitment is involved to number of comments. Virality is measured with the help of number of shares. Items of each measure is listed in Table 1. Both quantitatively and qualitatively stakeholders' mood were analyzed. Negative conversations (also understood as negative feedback) are the main reasons for some companies to avoid from social media [31].

Table 1. Metrics for Stakeholder Engagement

	Sign	Formula	Measures
Popularity	P1	Number of posts with likes/total posts	Percentage of the total posts that have been liked
	P2	Total likes/total number of posts	Average number of likes per post
	P3	(P2/number of fans)*1,000	Popularity of messages among fans
Commitment	C1	Number of posts with comments/total posts	Percentage of the total posts that have been commented on
	C2	Total comments/total posts	Average number of comments per post
	C3	(C2/number of fans)*1,000	Commitment of fans
Virality	V1	Number of posts with shares/total posts	Percentage of the total posts that have been shared
	V2	Total shares /total posts	Average number of shares per post
	V3	(V2/number of fans)*1,000	Virality of messages among fans
Stakeholder Engagement Index (E)	P3 + C3 + V3		

Kaynak: *[30]*

5. Findings

Out of 160 maritime shipping companies only 43 businesses have a local Facebook page, but 16 of these companies are inactive as they have never posted anything on their page by far. 21% of the companies posts only 1 to 5 posts, 21 % of them posts 6-29 posts, 16% have 30-100 posts and 5 % add over 100 posts through the year.

19 % of the companies' posts are related to the special days, events and occasions like Mothers Days, Cabotage Day, Feast etc. These posts are classified under the first category which is "special days". 76 % of the posts involve in corporate image of the company. These posts cover previous experiences, works on progress, in-firm promotions, advertisements or news about the company or employees, success stories and social responsibility projects supporting by them. This category is labelled as "corporate image". 1 % of the all posts are about sectoral news, new regulations and information like launching of a new port, changing export taxes etc. and these posts are labelled as "sectoral news", finally 4% of the posts make the announcements about fairs or events the companies are in and open positions in the company, so these posts are collected under the "announcements" category.

Although number of followers per company is 5466, average number of posts are only 59 and average number of comments made by followers are 38 which means every 66 posts take comments out of 100 posts. As seen in Table 2 average number of likes per company reaches to 5487 which is quite same with the number of followers. Finally, average number of the shared posts per company is 35 in the same period. It also reveals that from the statistics the order of top five companies according to number of followers and number of likes are quite similar. Number of Posts and Number of Liked posts are almost

Table 2. *Social Media Statistics of Maritime Companies*

	Followers (n)	Posts (n)	Liked Posts (n)	Comments (n)	Commented Posts (n)	Likes (Total) (n)	Shares (n)	Shared Posts (n)
Altun Lojistik Aş.	504	29	29	10	5	501	12	8
Batu International Lojistik	6.414	15	15	1	1	6.687	13	13
Borusan Lojistik	24.098	110	110	62	39	24.025	319	90
DSL Lojistik ve Uluslararası Taşımacılık	266	6	6	0	1	283	0	0
Fevzi Gandır Lojistik	1.119	81	81	17	11	1102	71	52
Galata Taşımacılık ve Tic.	2.764	53	53	12	6	2.777	48	44
Gezairi Transport Nak. Ve Tic.	2.076	10	10	36	10	2.081	90	10
Globelink Ünimar Lojistik	1.738	61	61	7	4	1.734	22	19
Hilal Trans Uluslararası Nak. ve Tic.	28.262	19	19	9	6	28.441	15	9
IMS Lojistik Uluslararası Taş.	1.177	20	20	6	3	1.185	6	5
Logitrans Lojistik	838	165	165	21	7	828	135	79
MTS Uluslararası Taş.ve Tic.	354	9	9	4	2	356	10	6
Sarp Intermodal Hiz.İç ve Dış Tic.	118	57	57	3	3	115	21	11
DB Schenker Arkas Nak.ve Tic.	10.317	120	120	283	76	10.248	3.141	73
Sertrans Uluslararası Nak. Tic.	1.958	121	121	100	85	1.956	90	100

same. Number of liked posts are nearly 4 times more than number of commented posts. Number of comments and number of shared posts are almost equal.

How many times posts are re-shared by followers are also examined under these four categories; special days, corporate image, sectoral news and announcements. It has shown that special days posts were re-shared 763 times, corporate image posts 3093 times, sectoral news posts 55 times and announcements 183 times by followers in total.

In Table 3 number of shares for each category are reported. It's obviously seen that posts about corporate image are shared by followers in a large extent. Additionally, in Borusan's page 90 posts were published and 280 people re-shared this post. Similarly, Gezairi published 10 posts but the posts related to corporate image were re-shared by 48 people. DB Schenkler has 73 posts in total and posts regarding corporate image were re-shared by 2499 individuals.

When the contents of the posts under these four categories are examined

Table 3. *Number of Re-shared Posts Per Category*

Number of Shares for Each Category	Content of Posts				
Company	Special Days	Corporate Image	Sectoral News	Announcements	Number of Shared Posts
Altun Lojistik Aş.	5	7	0	0	8
Batu International Lojistik	9	1	0	3	13
Borusan Lojistik	101	280	12	27	90
DSL Lojistik ve Uluslararası Taşımacılık	0	0	0	0	0
Fevzi Gandır Lojistik	20	43	0	8	52
Galata Taşımacılık ve Tic.	22	26	0	0	44
Gezairi Transport Nak. Ve Tic.	27	48	15	0	10
Globelink Ünimar Lojistik	3	14	2	3	19
Hilal Trans Uluslararası Nak.ve Tic.	1	14	0	0	9
IMS Lojistik Uluslararası Taş.	4	2	0	0	5
Logitrans Lojistik	19	108	0	8	79
MTS Uluslararası Taş.ve Tic.	3	4	0	3	6
Sarp Intermodal Hiz.İç ve Dış Tic.	3	17	0	1	11
DB Schenker Arkas Nak. ve Tic.	501	2.499	26	115	73
Sertrans Uluslararası Nak. Tic.	45	30	0	15	100
Average	55	220	14	20	35

following issues are noted;

- Most shared posts by followers under the category of “corporate image” are; work processes, new equipment, ships or new ports and new routes.
- Second most shared posts by followers under the category of “corporate image” are the posts related to staff and their success or promotions, in particular the posts tagged with specific names.
- Most shared posts by followers under the category of “special days” are the posts related to celebrations (national holidays, religious holidays and memorial days and cabotage day etc.) These posts are shared by followers to a large extent if the posts have no or very small logo on them.
- According to the media of the posts it is obviously seen that videos are much more shared by followers than photos.
- In special days category it is remarkably seen that the posts on celebrations are shared by followers to a large extent if the posts have no logo on them.

Additionally, metrics for stakeholder engagement levels are calculated and listed in Table 4. Top three companies according to their engagements level are Borusan, Logitrans and Galata respectively.

Table 4. *Customer Engagement Levels*

Company	P1	P2	P3	C1	C2	C3	V1	V2	V3	E
Altun Lojistik A.Ş.	1	445.80	69.50	0.87	0.07	0.01	0.87	0.87	0.14	70
Batu International Lojistik	1	218.41	9.06	0.82	0.56	0.02	0.82	2.90	0.12	9
Borusan Lojistik	1	47.17	177.32	0.00	0.00	0.00	0.00	0.00	0.00	177
DSL Lojistik ve Uluslararası Taşımacılık	1	13.60	12.16	0.64	0.21	0.19	0.64	0.88	0.78	13
Fevzi Gandur Lojistik	1	52.40	18.96	0.83	0.23	0.08	0.83	0.91	0.33	19
Galata Taşımacılık ve Ticaret	1	208.10	100.24	1.00	3.60	1.73	1.00	9.00	4.34	106
Gezairi Transport Nakliyat ve Ticaret	1	28.43	16.36	0.31	0.11	0.07	0.31	0.36	0.21	17
Globelink Ünimar Lojistik	1	1496.89	52.96	0.47	0.47	0.02	0.47	0.79	0.03	53
Hilal Trans Uluslararası Nakliyat ve Tic.	1	59.25	50.34	0.25	0.30	0.25	0.25	0.30	0.25	51
İMS Lojistik Uluslararası Taşımacılık	1	5.02	5.99	0.48	0.13	0.15	0.48	0.82	0.98	7
Logitrans Lojistik	1	39.56	111.74	0.67	0.44	1.26	0.67	1.11	3.14	116
MTS Uluslararası Taşımacılık ve Tic.	1	2.02	17.10	0.19	0.05	0.45	0.19	0.37	3.12	21
Sarp Intermodal Hizmetleri İç ve Dış Tic.	1	85.40	8.28	0.61	2.36	0.23	0.61	26.18	2.54	11
DB Schenker Arkas Nakliyat ve Ticaret	1	16.17	8.26	0.83	0.83	0.42	0.83	0.74	0.38	9
Sertrans Uluslararası Nakliyat Ticaret	1	194.00	46.00	0.55	0.65	0.37	0.55	3.04	1.14	48

Top three companies according to their engagements level are Borusan, Logitrans and Galata respectively.

6. Conclusion and Implications

B2C companies are using social media broadly when compared with B2B (business-to-business) companies. B2C companies use social media effectively to promote their brands and increase the number of fans. For that reason, customers can easily interact with other followers and with brand by using social media. On the other hand, B2B online communities are quite new. Such communities can professionally upload content and achieve collaboration with the stakeholders. It is known that B2B social media spending increased 46 percent yearly [32]. However, this amount might vary sector by sector.

In this study, exploratory research design was conducted to gain some insights on Facebook usage patterns of maritime businesses. Through content analysis, all the maritime businesses existing in Facebook were investigated in terms of the frequency and content of posts, comments and shares. Bonson and Ratkai 's (2013) social engagement metrics were used in order to calculate social media engagement. These metrics provide an insight to understand and measure social media usage of companies on Facebook [30]. In this research this metrics were applied for the first time to maritime transportation companies existing on Facebook.

According to the results of the analysis some essential issues are determined. First, this study confirms that Turkish maritime industry is not active on social media yet. Posts shared by companies are related to corporate image in a large extent. These posts consist of previous experiences, works on progress, in-firm promotions, advertisements or news about the company or employees, success stories and social responsibility projects. Posts on special days and celebrations follow the first category in a considerable extent. These findings show similarity with the findings of Çalışkan and Esmer [1]. They found that the main difference between Turkish and World port samples is the given importance on the celebration of special days (e.g., the celebration of festivals, special days such as Victory Day and Republic Day).

Secondly, from the engagement perspective it reveals that number of posts and number of liked posts are almost same. Number of liked posts are nearly 4 times more than number of commented posts. Number of comments and number of shared posts are almost equal. In line with the frequencies of posts according to their contents, corporate image posts are shared substantially, posts on special days and celebrations follow it, considerably.

Thirdly, posts with highest engagement average are the posts under the category of "corporate image" are on work processes, new equipment, ships or new ports and new routes, staff and their success or promotion. It seems that if the posts are tagged with specific names they are most likely shared by staff.

In special days category it is remarkably seen that the posts on celebrations are shared by followers to a large extent if the posts have no logo or have a small logo on them. Additionally, according to the media of the posts it is obviously seen that videos are much more shared by followers than photos.

Finally, for logistic companies average stakeholder engagement index was found 52 by Sürücü and Sakar in 2017 [27]. However, in the present study this index is found 18 for maritime transportation companies. It shows that maritime industry has a very small share in logistic sector in terms of social media usage efficiency.

For practical implication, maritime companies are suggested to be taken the advantage of Facebook accounts in the following issues; firstly, Facebook is the social network platform with more than 2 billion active users [33] interact with each other and organizations. Facebook is able to be used efficiently for updating schedules in real time, sharing the conditions that may negatively affect the delivery and sharing the resources (equipment, technology, software, staff etc.) of the company to emphasize corporate image as well. According to Andzulis et al. (2012) B2B companies should focus on developing long-term relationships rather than building short-term exchanges. Thus, maritime practitioners may utilize Facebook to build long-term relationship with their stakeholders. This will facilitate the process of communicating versatile messages to them. Being responsive, building trust, increased positive reputation and credibility [34, 35, 36] can be gained by sharing contents, photos and videos through Facebook.

This study should be considered under some limitations. As the number of the sample is only fifteen, a quantitative analysis couldn't be conducted to analyse the relationship between content type and engagement statistics. Forming the sample with posts instead of companies would provide a broader sample and future studies might investigate whether there is a relationship between and content type and stakeholder engagement level by quantitative research design. Commitment measure was calculated as the sum of all comments, yet it can be improved by separating positive and negative comments. Furthermore, content analysis can be repeated for other social media tools such as Twitter, Instagram and Linkedin.

References

[1] Çalışkan A. and Esmer S. (2018). Social Media Usage Patterns in Port Industry: Implications for Port Promotion and Public Relations, Journal of ETA Maritime Science, 6(1):61-74.

[2] Kho, N. (2008). B2B gets social media. EContent, 31(3): 26- 30.

[3] Social media (2018). Fishbat. Date of access: 02.10.2018 https://fishbat.com/services/social-media-agency/

[4] Mangold, W. G. and Faulds, D. J. (2009). Social media: The new hybrid element of the promotion mix. Business Horizons, 52(4):357-365.

[5] United Nations Conference on Trade and Development (2017). Review of Maritime Transport 2017. Date of access: 02.10.2018, https://unctad.org/

[6] Fafaliou, I., Lekakou, M. and Theotokas, I.(2006). Is the European shipping industry aware of corporate social responsibility? The case of the Greek-owned short sea shipping companies. Marine Policy, 30 (4):412–419.

[7] Hearn, G., Foth and M, Gray,H. (2009). Applications and implementations of new media in corporate communications: An action research approach. Corporate Communications: An International Journal, 14(1):49-61.

[8] Page, R., Barton, D., Unger, J.W. and Zappavigna M. (2014). Researching language and social media: A student guide. Routledge.

[9] Järvinen, J., Tollinen, A., Karjaluoto, H. and Jayawardhena, C. (2012). Digital and social media marketing usage in B2B industrial section. Marketing Management Journal, 22(2):102-117.

[10] Swani, K., Brown, B. P. and Milne, G. R. (2014). Should Tweets Differ for B2B and B2C? An Analysis of Fortune 500 Companies' Twitter Communications. Industrial Marketing Management, 43 (5):873-881.

[11] Michaelidou, N., Siamagka, N. T., and Christodoulides, G. (2011). Usage, barriers and measurement of social media marketing: An Exploratory Investigation Of Small And Medium B2B Brands. Industrial Marketing Management, 40(7):1153-1159.

[12] North Venture Partners, (2009) Nine Ways Your Business Could Be Using Social Media, But Probably Isn't. Brandchannel. Retrieved January 22, 2011, from http://www.brandchannel. com/ images/ papers/ 460_Nine_Ways.pdf.

[13] Katona Z. and Sarvary M. (2014). Berkeley-Haas Case Series Maersk Line: B2B Social Media- It's Communication, Not Marketing. California Management Review, 56(3):142–156.

[14] Huotari, L., Ulkuniemi, P., Saraniemi, S. and Mäläskä, M. (2015). Analysis Of Content Creation İn Social Media By B2B Companies. Journal of Business & Industrial Marketing, 30 (6):761-770.

[15] Walters, P. G. (2008). Adding Value In Global B2B Supply Chains: Strategic Directions And The Role Of The Internet As A Driver Of Competitive Advantage. Industrial Marketing Management, 37(1):59–68.

[16] Gupta, S., Balmer, J. M. T. and Low, B. (2015). Brands In, From And To Emerging Markets: The Role Of Industrial Relationships. Industrial Marketing Management, 51: 4–10.

[17] Brennan, R. and Croft, R. (2012). The Use Of Social Media In B2B Marketing And Branding: An Exploratory Study. Journal of Consumer Behaviour, 11(2):101-115.

[18] Mehmet, M and Clarke, R. J. (2016). B2B Social Media Semantics: Analysing Multimodal Online Meanings In Marketing Conversations. Industrial Marketing Management 54:92-106.

[19] Siamagka, N.-T., Christodoulides, G., Michaelidou, and N., Valvi, A. (2015). Determinants Of Social Media Adoption By B2B Organizations. Industrial Marketing Management 51: 89–99.

[20] Andersson,S. and Wikström,N. (2017). Why And How Are Social Media Used In A B2B Context, And Which Stakeholders Are Involved?. Journal of Business & Industrial Marketing, 32(8):1098-1108.

[21] Valos,M., Polonsky,J. Mavondo, M and Lipscomb, J. (2015). Senior Marketers' Insights Into The Challenges Of Social Media Implementation In Large Organisations: Assessing Generic And Electronic Orientation Models As Potential Solutions. Journal of Marketing Management, 31 (7-8) :713-746.

[22] Ferrell, O. C., Gonzalez-Padron, T. L., Hult, G. T. M. and Maignan, I. (2010). From Market Orientation To Stakeholder Orientation. Journal of Public Policy and Marketing, 29(1):93–96.

[23] Bruce, P., and Shelley, R. (2010). Assessing Stakeholder Engagement. Communication Journal of New Zealand, 11:30–48.

[24] Kuvykaite R. and Piligrimi, Z. (2013). Communication In Social Media For Company's Image Formation. Economics and Management. 18 (2):305-317.

[25] Gorry, G.A. and Westbrook, R.A. (2011). Can You Hear Me Now? Learning From Customer Stories. Business Horizons, 54(6):575-584.

[26] Manetti, G., Bellucci, M. and Bagnoli, L. (2016). Stakeholder Engagement and Public Information Through Social Media: A Study of Canadian and American Public Transportation Agencies, American Review of Public Administration, 47(8):991-1009.

[27] Sürücü, E. and Denktaş-Şakar, G. (2018). Sosyal Medya Araciliğiyla Paydaş Katiliminin Ölçülmesi: Türk Lojistik Hizmet Sağlayan İşletmeler Üzerine Bir İnceleme, Dumlupınar Üniversitesi Sosyal Bilimler Dergisi, 8 :107-129.

[28] Metushi E., Fradeani A. (2019). Company Reporting on Social Media: A Content Analysis of the Albanian Companies. In: Lazazzara A., Nacamulli R., Rossignoli C., Za S. (eds) Organizing for Digital Innovation. Lecture Notes in Information Systems and Organisation, Vol 27. Springer, Cham.

[29] Hsieh, H.-F. and Shannon, S. E. (2005). Three Approaches to Qualitative Content Analysis. Qualitative Health Research, 15(9):1277–1288.

[30] Bonsón, E., and Ratkai, M. (2013). A Set Of Metrics To Assess Stakeholder Engagement And Social Legitimacy On A Corporate Facebook Page. Online Information Review, 37(5):787-803.

[31] Ralphs, M. (2011). Built In Or Bolt On: Why Social Currency Is Essential To Social Media Marketing. Journal of Direct, Data and Digital Marketing Practice, 12 (3):211-215.

[32] https://www.b2bmarketing.net/en-gb/resources/news/social-media-ad-spend-increase-235-billion-202. Date of access: 05.10.2018

[33] Nowak,M.,and Spiller,G.(2017). Two billion people coming together on Facebook. Retrieved from https://newsroom.fb.com/news/2017/06/two-billion-people-coming-together-on-facebook/ Date of access: 26.03.2019

[34] Agnihotri, R., Kothandaraman, P., Kashyap, R., and Singh, R. (2012). Bringing "Social" Into Sales: The Impact Of Salespeople's Social Media Use On Service Behaviors And Value Creation. Journal of Personal Selling & Sales Management, 32(3):333–348.

[35] Andzulis, J., Panagopoulos, N., and Rapp, A. (2012). A Review Of Social Media And Implications For The Sales Process. Journal of Personal Selling & Sales Management, 32(3):305–316.
[36] Lacoste, S. (2016). Perspectives On Social Media And Its Use By Key Account Managers. Industrial Marketing Management, 54:33–43.

This Page Intentionally Left Blank

Received: 27 December 2018 *Accepted: 15 May 2019* *DOI ID: 10.5505/jems.2019.30643*

Journal of ETA Maritime Science

JEMS JOURNAL

Corresponding Author: Murat Selçuk SOLMAZ

Yenilenebilir Enerjinin Gemilerde Kullanılması: Bir Yağ Barcına Kurulan Hibrit Sistemin Ekonomik ve Çevresel Analizi ile Optimizasyonu

Murat Selçuk SOLMAZ[1], Alparslan BAŞKAYA[2], Atilla SAVAŞ[3], Mehmet AKMAN[1]

[1]Pîrî Reis Üniversitesi, Denizcilik Fakültesi, Türkiye
[2]Pîrî Reis Üniversitesi, Fen Bilimleri Enstitüsü, Türkiye
[3]Pîrî Reis Üniversitesi, Mühendislik Fakültesi, Türkiye
mssolmaz@pirireis.edu.tr ORCID ID: https://orcid.org/0000-0002-8528-2865
alparslan.baskaya@marpolidenizcilik.com; ORCID ID: https://orcid.org/0000-0002-1937-899X
asavas@pirireis.edu.tr; ORCID ID: https://orcid.org/0000-0001-6900-3259
makman@piririeis.edu.tr; ORCID ID: https://orcid.org/0000-0002-6274-2742

Öz

Artan enerji talebi, akaryakıt fiyatları ve fosil yakıtlardan kaynaklanan olumsuz çevresel etkiler, yenilenebilir ve sürdürülebilir enerjiye olan talebi artırmaktadır. Bu nedenle, rüzgâr ve güneş enerjileri günlük hayatta kullanılabilir hale gelmiş ve bu tür sistemlerin verimliliği konusunda çalışmalar hızlanmıştır. Denizcilik sektöründe de benzer bir durum yaşanmış ve yakın zamanda yenilenebilir enerji gemiler için popüler hale gelmiştir. Bu çalışmada, yakıt tüketimini ve çevre kirliliğini azaltmak amacıyla çalışma zamanının çoğunu demirde ya da iskelede geçiren bir barca rüzgâr ve güneş enerjisini kaynak olarak kullanan yenilenebilir hibrit bir enerji sistemi kurulmuştur. Kurulan sistem HOMER yazılımı ile optimize edilen konfigürasyonlarla mukayese edilmiştir. Sonuçlara göre, hibrit sistemin gemide kullanılmasıyla hesaplarda dikkate alınan süreçte yakıt tüketiminde ve emisyonlarda yaklaşık %39 oranında azalma sağlanmıştır. Sistemin geri ödeme süresi ise yaklaşık iki yıl olarak hesaplanmıştır.

Anahtar Kelimeler: *Yenilenebilir Enerji Kaynakları, Emisyon, Enerji Tasarrufu, Gemi İşletmeciliği, HOMER.*

Utilization of Renewable Energy in Ships: Optimization of Hybrid System Installed in an Oil Barge with Economical and Environmental Analysis

Abstract

Increasing energy demand, fuel prices and adverse environmental impacts from fossil fuels increase demand for renewable and sustainable energy. For this reason, wind and solar energies have become available in daily life and work on the efficiency of such systems has accelerated. A similar situation has occurred in the maritime sector and recently renewable energy has become popular for ships. In this study, a hybrid renewable energy system that uses wind and solar energy as a source was installed to reduce fuel consumption and environmental pollution for a barge, which spends its time mostly at anchorage or at port. The installed system was compared to the optimized configurations with HOMER software. According to results, by using the hybrid system onboard, it is possible to achieve a 39% reduction in fuel consumption and emissions at given period and conditions. The return of investment period of the system was calculated as about two years.

Keywords: *Renewable Energy Sources, Emission, Energy Saving, Ship Management, HOMER.*

To cite this article: Solmaz, M. S., Başkaya, A., Savaş, A. & Akman, M. (2019). Yenilenebilir Enerjinin Gemilerde Kullanılması: Bir Yağ Barcına Kurulan Hibrit Sistemin Ekonomik ve Çevresel Analizi ile Optimizasyonu. *Journal of ETA Maritime Science*, 7(2), 179-191.
To link to this article: https://dx.doi.org/10.5505/jems.2019.30643

1. Giriş

Dünya ticaret hacmindeki artışa bağlı olarak denizcilik sektörü de gelişmektedir. Deniz yoluyla yapılan taşımacılıktaki hacimsel büyüme 1950'li yıllara kıyasla 100 kat daha fazladır [1]. Yakıt fiyatlarının ise 1980'li yıllara oranla üç kat arttığı ve yakıt maliyetinin gemi tipine göre toplam işletme giderlerinin % 43'ü ile % 67'si arasında olduğu bilinmektedir [2]. Büyük çoğunluğunun dizel makinalarla tahrik edildiği gemilerde, kullanılan yakıta bağlı olarak yanma işleminin sonunda ortaya çıkan azot oksit (NO_X), kükürt oksit (SO_X), karbon monoksit (CO), karbondioksit (CO_2), partikül madde (PM) ve hidrokarbon (HC) gibi kirleticiler ulusal ve uluslararası ortamda çevre için bir tehdit oluşturmaktadır. Emisyonlar; asit yağmurlarına, ozon tabakasında incelmeye, çevreye verdikleri zararlara ve canlı yaşamına tehdide sebep olmalarından dolayı, emisyonların kontrolü ve en aza indirilmesi önemlidir. 2007 yılında insan aktiviteleri kaynaklı küresel karbondioksit (CO_2) dağılımı; elektrik ve ısıtma için % 35, ulaşım için % 27, sanayi için % 22,8 ve % 15,2 diğer kullanımlar olarak verilen çalışmada, gemi kaynaklı taşımacılığın payı % 3,3'tür [3]. Denizcilikteki enerji talebine bağlı olarak artan gemi taşımacılığı için 2050 yılına gelindiğinde ton-mil bazında büyümenin % 147 ile % 302 arasında olacağı tahmin edilmektedir ve bu büyüme, herhangi bir önlem alınmadığı takdirde 2007 yılına kıyasla, karbon dioksit (CO_2) salınımını % 400 artıracaktır [3]. Bu nedenle, gemi emisyonlarını azaltmak ve enerji verimliliğini artırmak maksadıyla çeşitli düzenlemeler yürürlüğe sokulmuştur. Bu düzenlemeler kapsamında emisyon kontrol bölgeleri oluşturulmuş, bu bölgelerde ilk limitlere göre azot oksit (NO_X) emisyon değerinin % 80, kükürt oksit (SO_X) emisyon değerinin % 90 azaltılması amaçlanmıştır [4]. Gemi emisyonlarının azaltılması için gerekli düzenlemeler, Denizlerin Gemiler Tarafından Kirletilmesinin Önlenmesine Ait Uluslararası Sözleşme (MARPOL 73/78)'nin "Gemilerden Kaynaklanan Hava Kirliliğinin Önlenmesi Kuralları"nı içeren VI numaralı ekinde belirtilmiştir. Ayrıca, aynı düzenlemeye göre 400 gros tondan büyük tüm gemiler için "Gemi Enerji Verimliliği Yönetim Planı"nın hazırlanması zorunlu hale getirilmiştir. Bu sebeple, fosil yakıtların ekonomik ve ekolojik olumsuz etkileri yenilenebilir enerji sistemlerine olan talebi artırmıştır. Foto-voltaik (PV) sistemler, rüzgâr türbinleri, mikro-hidro (MH) sistemler ve yakıt hücreleri (FC) gibi yenilenebilir enerji sistemleri, yakıt tasarrufu ve emisyonlarda azalma sağladıklarından tercih edilmekte ve bu sistemler üzerine araştırma ve geliştirme faaliyetleri hız kazanmaktadır.

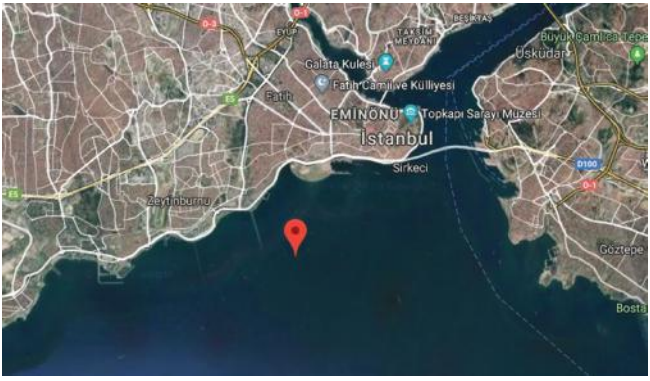
Bu konuda daha önce yapılmış çalışmalar incelendiğinde müteakip sonuçlara ulaşılmaktadır. Adaramola ve diğ. Gana için bir PV-rüzgâr türbini-dizel-akü sistemini modellemiş, aynı zamanda rüzgâr hızı, güneş küresel radyasyon ve dizel fiyat parametrelerini değiştirerek bir duyarlılık analizi yapmıştır [5]. Bernal ve Lopez, en yaygın sistemlerin, kurşun asitli bataryalar ile PV jeneratörleri ve/veya rüzgâr türbinleri ve/veya dizel jeneratörleri olduğunu bildirmiştir [6]. PV-batarya-rüzgâr türbini ve batarya bağımsız yenilenebilir enerji sistemleri Askari ve Ameri tarafından analiz edilmiştir [7]. HOMER optimizasyon analizinden sonra, Kerman-İran'da PV-batarya sisteminin yenilenebilir enerji sistemi gereksinimleri için en uygun çözüm olduğu tespit edilmiştir. Khan ve diğ., Tioman Adası-Malezya'daki şebekeye bağlı yenilenebilir enerji sistemini incelemiş ve en uygun sistemin PV-hidro- dizel-batarya sistemi olduğunu tespit etmişlerdir [8]. Aynı çalışmada, HOMER yazılımı ile bir hassasiyet analizi yaparak ve değişen dizel yakıt fiyatı, yıllık yük profili, yıllık ortalama su akışı ve yıllık faiz oranının etkisini analiz etmişlerdir. Bağımsız bir PV-rüzgâr hibrid sistemi boyutlandırması Belmili ve diğ. tarafından analiz edilmiştir [9]. Bu kapsamda hedef odaklı programlama yoluyla tekno-ekonomik analizini yapmışlardır. Bhattacharjee ve Acharya, Tripura-Hindistan'da bulunan küçük ölçekli bir PV-rüzgâr-batarya yenilenebilir enerji sistemi için tekno-ekonomik fizibilite analizini yapmışlardır [10]. 3-5 kW aralığında olan bu küçük ölçekli sistem, bu yazıda sunduğumuz gemi sistemimize çok benzer bir sistemdir. Givler ve Lilienthal, Sri Lanka'daki dizel jeneratörlerinin küçük foto-voltaik sistemlerindeki rolünü araştırmak için HOMER yazılımının uygulamasını gösteren bir rapor sunmuştur [11]. İsmail ve diğ. HOMER yazılımını kullanarak Malezya'da PV-dizel-batarya hibrid sistemini modellemiştir [12]. Çalışmalarında üç farklı senaryo inceleyerek, PV panellerden, bir batarya bankından ve dizel jeneratörden oluşan hibrid sistem senaryosunun, ekonomik açıdan en uygun olduğunu bulmuşlardır. Kaabeche ve Ibtiouen, Ghardaia-Cezayir'de bulunan PV-rüzgâr türbini-dizel-batarya sistemi için bir tekno-ekonomik analiz yapmıştır [13]. Yazarlar PV-rüzgâr türbini-dizel-batarya sistemini, PV-rüzgâr-batarya ve sadece dizel sistemlerinden daha ekonomik olarak bulmuşlardır. Kalıncı ve diğ. Türkiye'de Bozcaada'da hidrojen üretimi ve depolanması ile yenilenebilir enerji sistemi için HOMER yazılımı ile tekno-ekonomik analizi gerçekleştirmiştir [14]. Yazarlar simülasyonun hibrid yenilenebilir enerji sisteminin yakıt pili ile kullanılmasının teknik açıdan uygun olduğunu gösterdiğini, ancak bunun Türkiye için pahalı bir yöntem olduğu sonucuna varmışlardır. Kavala-Yunanistan'da bağımsız PV-dizel-batarya-FC sisteminin tekno-ekonomik analizi Karakoulidis ve diğ. tarafından analiz edilmiştir [15]. Çalışmada, net mevcut maliyet yöntemine dayanarak sistemlerin optimal kombinasyonunu belirlemek için PV, dizel jeneratörler ve bataryaların farklı kombinasyonları seçilmiştir. Optimizasyon, HOMER yazılımı ile gerçekleştirilmiştir. Lau ve diğ. Malezya'da bulunan PV-dizel yenilenebilir enerji sisteminin performans analizini HOMER yazılımı ile gerçekleştirmiştir [16]. Çalışmada hassasiyet analizi, değişen dizel fiyatı ve ışınım parametreleri ile yapılmıştır. Mohamed ve diğ. Brest-Fransa şehrine enerji sağlamak için kurulan PV-FC yenilenebilir enerji sisteminin analizini yapmışlar ve HOMER yazılımı ve Brest şehrinin yük talep profilini ve gerçek hava durumu verilerini kullanmışlardır [17]. Ramli ve diğ., çalışmalarında tamamen farklı bir enerji depolama sistemini denemiştir [18]. Suudi Arabistan'daki Mekke şehri ile ilgili yapmış oldukları çalışmada, mekanik enerjiyi PV/dizel/volan sistemlerinde 5-30 saniye saklamak için volan kullanmışlardır. Rehman ve diğ., Rafha-Suudi Arabistan'da bulunan bir PV-dizel-akü sistemini incelemiştir [19]. Artan yakıt fiyatı ile birlikte dizelin hibrit güç sistemiyle karşılaştırıldığında dizelin en pahalı sistem olduğunu belirtmişlerdir. Rohani ve Nour, Birleşik Arap Emirliklerindeki Ras Musherib için bir bağımsız hibrid yenilenebilir enerji sisteminin tekno-ekonomik analizini yapmıştır [20]. Çalışmalarındaki optimizasyon sonuçları, son birkaç yılda yakıt fiyatının artması nedeniyle, çalışmada incelenen yerlerin çoğunda, hibrid yenilenebilir enerji sisteminin geleneksel sistemden daha uygun olduğunu göstermiştir. Kumar ve Manoharan, Tamil Nadu-Hindistan'daki PV/dizel sistemini araştırmak için HOMER yazılımını kullanmışlardır [21]. Yazarlar, hibrid sistemlerin uygulanmasının başlangıç maliyetlerinin yüksek olmasından dolayı, Tamil Nadu'da yenilenebilir enerji sektöründeki yatırımları teşvik etmek için hükümet sübvansiyonları ve tarife imtiyazının, kırsal alandaki elektrifikasyon problemlerini ve atmosferdeki karbondioksit seviyelerini azaltmaya yardımcı olmak için yapılması gerektiği sonucuna varmışlardır. Türkay ve diğ. İstanbul-Türkiye'de bulunan PV-rüzgâr-FC sistemini incelemiştir [22]. Hem şebekeye bağlı hem de bağımsız kombinasyonu analiz etmişlerdir. Yenilenebilir enerji sistemlerinin yüksek başlangıç yatırım maliyeti ve kaynak bağımlılığının, bu teknolojilerin tanıtımını büyük ölçüde engelleyen ana engel olduğu tespitini yapmışlardır. Teknolojinin gelişmesi ve maliyetlerdeki düşüş ile birlikte ortaya çıkacak olan bilimsel ve teknolojik ilerleme, bu sistemlerin potansiyelini sürekli olarak artıracaktır. Öte yandan, düşük bakım maliyetleri, talep artışı durumunda talebi karşılama potansiyeli ve cazip geri ödeme süreleri bu sistemlerin avantajı olarak tespit edilmiştir.

Yenilenebilir enerji sistemlerinin gemi üzerindeki uygulamaları konusunda literatür araştırması yapıldığında şu örneklere rastlanmıştır: Wen ve diğ., bir gemi için foto-voltaik bir enerji üretim sistemi modeli ortaya koymuşlardır [23]. Bir yelkenli teknede içten yanmalı makine yerine çeşitli yenilenebilir enerji kaynaklarının kullanıldığı ve modellendiği bir çalışmayı Alfonsin ve diğ. gerçekleştirmiştir [24]. Evrin ve Dinçer gemiler için hidrojen yakıt hücresi sisteminin termodinamik analizini ve değerlendirmesini yapmıştır, bu çalışma katı oksitli yakıt hücresinin enerji ve ekserji performansını da içermektedir [25]. Hibrid gemi enerji sisteminin (güneş enerjisi ve dizel jeneratör) deneysel incelemesi Yuan ve diğ. tarafından gerçekleştirilmiştir. Güneş enerjili hibrid sistem sayesinde yıllık olarak, yakıt tüketiminde % 4.02 ve karbon salınımında ise % 8.55 düşüş sağlanmıştır [26]. Diab ve diğ. foto-voltaik sistem/dizel jeneratör/batarya hibrid yenilenebilir sistemin gemi ve karada uygulamaları için bir çalışma yapmışlardır. Optimum sistemin sadece % 5.7 yenilenebilir kısım içermesi gerektiği, aynı zamanda 25 senelik ömrü boyunca sismetin 9.735.000 kg daha az sera gazı salınımı yaptığı sonucuna varılmıştır [27].

Bu çalışmada, Bahri Ege isimli yağ barcına kurulmuş hibrid PV-rüzgâr-akü yenilenebilir enerji sistemi simüle edilmiş ve sistem HOMER yazılımı ile optimize edilen konfigürasyonlarla mukayese edilmiştir. Optimizasyon için geminin yük profili kullanılmış ve İstanbul'un gerçek hava durumu verileri HOMER yazılımına veri olarak girilmiştir. Araştırmanın sonunda dizel yakıt fiyatının, güneş enerjisi ve rüzgâr hızı verileri ile bir hassasiyet analizi yapılmıştır.

2. Geminin Operasyon Bölgesinin Yenilenebilir Enerji Açısından İncelenmesi

Gemi, 41° 00' 15'' K – 028° 56' 50'' D, 40° 58' 15'' K – 028° 56' 50'' D, 40° 56' 82'' K –



Şekil 1. *Geminin Bekleme Bölgesinin Uydu Görüntüsü [28]*

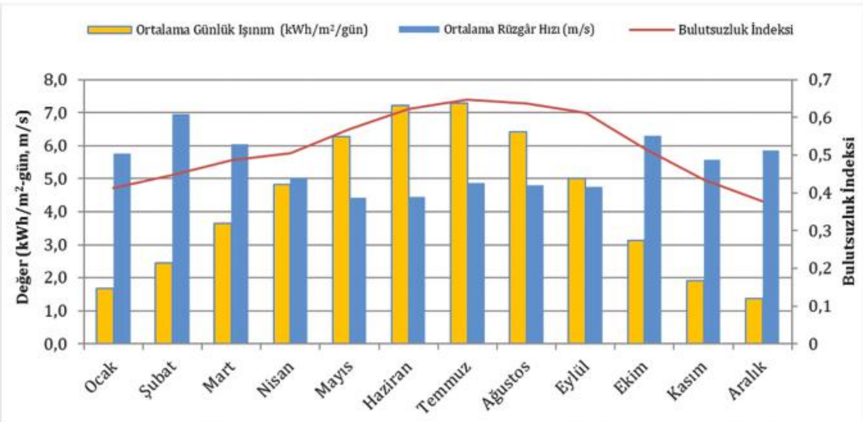
028° 53' 50'' D ve 40° 58' 92'' K – 028° 53' 50'' D koordinatları arasında, Marmara Denizi-Zeytinburnu açıklarında çalışmaktadır. Ölçümlerin yapıldığı bekleme bölgesinin yaklaşık koordinatı ise 40° 58' 26,41'' K – 28° 56' 24,64'' D'dir. Koordinatları verilen bölgenin uydu görüntüsü Şekil 1'dedir.

Sistemin modellenmesi ve üreteceği enerjinin tahmin edilmesi için bir yıl için ortalama günlük güneş ışınımı, bulutsuzluk indeksi ve rüzgâr hızı değerlerinin değerlendirilmesi gerekmektedir. Bu amaçla Zeytinburnu bölgesine ait HOMER yazılımından elde edilen veriler incelenmiştir (Şekil 2). Güneş ışınımı değeri, çalışma bölgesinde günlük bazda metrekare başına düşen ışınım gücünün kWh cinsinden ifadesidir. Bulutsuzluk indeksi aylık bazda güneşlenme oranını, rüzgâr hızı ise aylık bazda ortalama rüzgâr hızını ifade eder.

gerekli olduğunu göstermektedir. Bölgedeki ortalama rüzgâr hızının 5,5 m/s olduğu ve hızın yaz aylarında azaldığı görülmektedir. Şubat ve Ekim aylarında bölgenin rüzgâr hızı azami değerine ulaşmaktadır.

3. Barç Üzerinde Yenilebilir Enerji Sisteminin Modellenmesi ve Analizi

Yenilenebilir enerji sistemi, Tablo 1'de özellikleri verilen Bahri Ege isimli barca kurulmuş ve sistem 14.11.2013 tarihinde çalıştırılmıştır. 28.02.2014 - 23.04.2014 tarihleri arasında akülerin yetersizliği sebebi ile sistem arıza yapmış ve yeni akülerin getirilmesi için sistem devre dışı bırakılarak tekrar jeneratör kullanılmıştır. Sistemin onarılması ve akülerin ilave edilmesi ile 23.04.2014 tarihinden sonra sistem tekrar kullanılmaya başlanmıştır. Elde edilen gerçek veriler HOMER yazılımı ile optimize edilen konfigürasyonlarla mukayese edilmiştir.



Şekil 2. Zeytinburnu Bölgesi Ortalama Günlük Işınım, Bulutsuzluk İndeksi (B.İ.) ve Ortalama Rüzgâr Hızı Değerleri

İlgili bölgenin güneş enerjisi profiline bakıldığında, yaz aylarında güneş ışınım şiddetinin artış gösterdiği görülmektedir. Tüm yılın günlük ortalama ışınım şiddetinin ise 4,27 kWh/m^2/gün olduğu görülmektedir. Kış aylarındaki ışınım şiddeti düşüşü, güneş enerjisi yanında rüzgâr enerjisi kullanımının ne kadar

Tablo 1. *Bahri Ege Barcının Özellikleri*

Özellik	Değer
IMO No	8741624
Tipi	Yağ Barcı
Yapım Yılı	1983
Gros Ton / DWT	197 gt. / 324 ton
Boy / Genişlik	42,07 m / 6 m

Gemide bulunan cihazların elektrik yükleri Tablo-2'de verilmiştir. Bu yükler, gemi aborda/demirli olduğu durumda, içerisinde bulunan liman jeneratörü tarafından karşılanmaktadır. Toplam elektrik yükü tüm ekipmanlar devrede olduğunda 29,874 kW olarak hesaplanmıştır. HOMER yazılımı ile alınan ölçüm verilerine göre, barçta kullanılan günlük elektrik enerjisi tüketim miktarı ise yaklaşık olarak 17,57 kW'tır.

Liman jeneratörüne ait bilgiler Tablo-3'te verilmiştir. Liman jeneratörünün tam yükte yakıt tüketimi 10,4 lt/h iken, ortalama yakıt tüketimi ölçüm sonuçlarına göre 5 lt/h elde edilmiştir.

Gemide enerjiye sürekli ihtiyaç duyulmakta, gece saatlerinde ise aydınlatma ihtiyacına bağlı olarak elektrik enerjisi talebi artmaktadır. Gemide bulunan elektrik yüklerini karşılamak amacıyla gemiye kurulan yenilenebilir enerji sisteminin şematik gösterimi ve HOMER modeli Şekil 3'de verilmiştir.

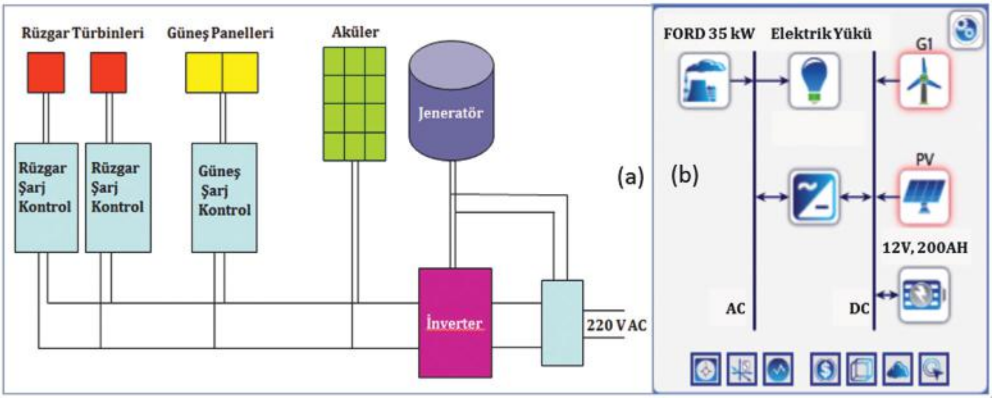
Barca monte edilen yenilenebilir enerji sistemi; 2 adet rüzgâr türbini (2x1000 W), 2 adet güneş paneli (2x230 W), 4 adedi sonradan ilave edilen 12 adet jel akü (200 AH, 12 V, 2400 W) ve 1 adet inverter (5000 W)'den oluşmaktadır (Şekil 4). Aküler, geminin seyri esnasında FORD 170 model 127 kW'lık servis jeneratörü tarafından da doldurulmaktadır. Servis jeneratörünün yakıt tüketimi ortalama 18 lt/h'tir.

Tablo 2. *Barçta Kullanılan Ekipmanlar ve Güçleri*

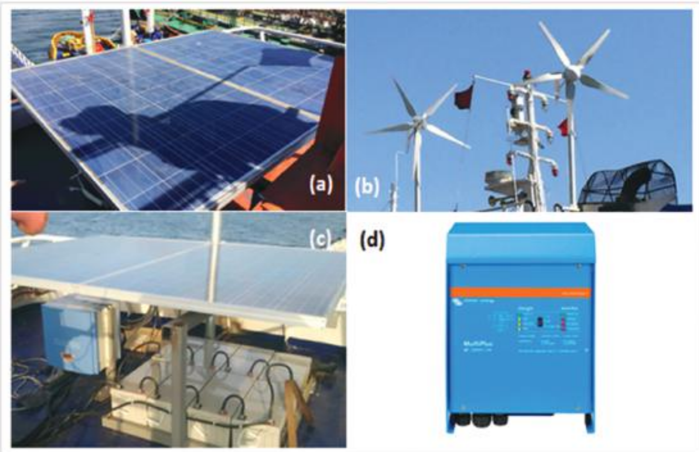
Adet	Ekipman	Güç (W)	Adet	Ekipman	Güç (W)
1	TV 55 Ekran	150	1	Kahve Makinası	2200
1	Güçlendirici	1500	-	Köprüüstü Aletleri	3500
3	Mini Soğutucu (750 W/adet)	2250	1	Dizüstü bilgisayarı	74
1	Dondurucu	500	3	Projektör (1000 W/adet)	3000
4	Elektrikli Isıtıcı (800 W/adet)	3200	3	Projektör (500 W/adet)	1500
2	Elektrikli Ocak (1500 W/adet)	3000	1	Saç Kurutma Makinesi	400
30	Ampul (60 W/adet)	1800	1	Su Isıtıcısı	6000
20	Flüoresan (40 W/adet)	800		**TOPLAM**	**29874**

Tablo 3. *Barçta Kullanılan Liman Jeneratörünün Özellikleri ve Kabuller*

Özellik	Değer	Özellik	Değer
Modeli	Ford DG 4-stroke	Yakıt alt ısıl değeri	43979 kj/kg.
Güç faktörü	0,8	Yakıt yoğunluğu	0,779 kg/lt
Elektrik frekansı	50 Hz.	Mekanik verimi	% 75
RPM	1500	Jeneratör verimi	% 97
Bekleme gücü	50 kVA	Toplam verim	% 72,8
Maksimum güç	40 kW	Yakıtın ısıl gücü	54,98 kW
Dizel yakıt türü	Marine Diesel Oil	Özgül yakıt tüketimi (%100 yük)	203 g/kWh



Şekil 3. Yenilenebilir Enerji Sistemin Şematik Gösterimi (a) ve HOMER Modeli (b)



Şekil 4. Güneş Panelleri (a), Rüzgâr Türbinleri (a), Aküler (c) ve İnverter (d)

Tablo 4. Sistemde Kullanılan Yenilenebilir Enerji Sisteminin Elemanlarının Teknik Özellikleri

Sistem elemanı	Teknik özellikleri
Rüzgâr türbini	Gücü: 1000 W, voltajı: 24/48 VDC (şebekeden bağımsız), 48/110 VDC (şebeke üzerinde), pervane kanat sayısı: 5, çalışma rüzgâr sürati: 12 m/s, çalışabileceği azami rüzgâr sürati: 50 m/s, ağırlığı: 28 kg, boyutları: 1460 x 530 x 260 mm.
Güneş paneli	Gücü: 230 W, azami voltaj: 29,5 V, azami akım: 7,8 A, azami sistem voltajı:1000 V, ağırlığı:20 kg, boyutları: 1640 x 990 x 50 mm.
Jel akü	200 AH, 12 volt, iç rezistansı: 2,7 mili ohm, ağırlığı: 66 kg, boyutları: 522 x 240 x 224 mm.
İnverter	Giriş voltajı (DC): 9,5 – 17 V, 19 – 33 V, 38 – 66 V, çıkış voltajı (AC): 230 V ± % 2, frekansı: 45 – 65 Hz, ağırlığı: 30 kg, boyutları: 444x328x240 mm.

Sistemde kullanılan yenilenebilir enerji sisteminin elemanlarının teknik özellikleri Tablo 4'te olduğu gibidir.

Çalışmada kullanılan HOMER yazılımı şebekeye bağlı ya da bağımsız çalışacak bir çok güç sisteminin dizayn edilmesinde kullanılan bir simülasyon ve optimizasyon yazılımıdır. Yazılım, enerji dengesi hesaplamalarını yaparak sistemin çalışmasını her bir zaman adımı için simüle etmekte, her zaman adımında, elektrik ve ısıl talebi, sistemin o zaman adımında sağlayabileceği enerjiyle karşılaştırmakta ve sistemin her bir bileşeninden enerji akışını hesaplamaktadır. Tüm olası sistem yapılandırmalarını simüle ettikten sonra yazılım, sistem tasarım seçeneklerini karşılaştırmak için kullanabilecek net mevcut maliyete göre sıralanmış bir yapılandırma listesi görüntülemektedir. Simülasyon için kullanılan modelde ekonomik analiz için HOMER yazılımı, yatırım maliyeti, sistem bileşeni değişim maliyeti, operasyon ve bakım maliyeti, yakıt maliyeti ve kurtarma değeri parametrelerine bağlı olarak hesap yapmaktadır.

HOMER yazılımı ekonomik analizi yaparken mevcut net maliyete (NPC) göre sıralar. Yazılım, tüm fiyatların sistem ömrü boyunca aynı oranda artacağını varsayar. Bu varsayımla enflasyon, gelecekteki nakit akışlarını bugüne indirgerken, nominal faiz oranından ziyade reel (enflasyona göre düzeltilmiş) faiz oranını kullanarak analizden çıkarılabilir. NPC aşağıdaki denklem ile hesaplanabilir;

$$NPC = C_{ann,t}/CRF_{i,R_{sis}} \tag{1}$$

burada $C_{ann,t}$ yıllık toplam maliyeti, *CRF* anaparanın geri kazanım oranı ve R_{sis} sistem ömrünü ifade eder. Hesaplarda ömür değeri 25 yıl alınmıştır [10]. *CRF* aşağıdaki ifadeyle hesaplanabilir;

$$CRF(j,N) = (1+j)^N/[j(1+j)-1] \tag{2}$$

burada *j* yıllık yıllık faiz oranını, *N* ise yıl sayısını ifade eder. Bir başka önemli ekonomik parametre de sistemde üretilen elektrik enerjisinin kWh başına maliyetidir (COE). Analizlerde proje ömrü 25 yıl ve yıllık reel faiz % 6 olarak alınmıştır [10]. Enerji maliyeti ise;

$$COE = C_{ann,t}/(E_{prim} + E_{def}) \tag{3}$$

burada E_{prim} ana elektrik yükünü, E_{def} ertelenebilir elektrik yükünü ifade eder. Paydadaki kısım sistemin sağladığı elektrik yüküdür.

Yenilenebilir enerjinin gemide kullanılması, jeneratörün elektrik yükünü azaltacağından yakıt tasarrufu sağlanacaktır. Sistemden sağlanan yakıt tasarrufu (FS) kütle cinsinden [29];

$$FS = \frac{\dot{W}_e.(t_{opr,i} - t_{opr,f})}{\eta_m.\eta_g}.SFOC \tag{4}$$

ifadesiyle bulunabilir. Burada $\dot{W}_e$ sağlanan elektrik gücünü (kW), η_m mekanik verimi, η_g jeneratör verimini ve SFOC kg/kW-h cinsinden yakıt tüketimini, $t_{opr,i}$ ilk durumdaki çalışma süresini, $t_{opr,f}$ ise son durumdaki çalışma süresini ifade eder. Bu çalışmada mekanik verim 0.75, jeneratör verimi 0.97 alınmıştır.

Yakıt tasarrufunun emisyonlar cinsinden değeri (ES) emisyon faktörlerinin kullanılması ile hesaplanabilir.

$$ES = \frac{\dot{W}_e.t_{opr}.X_E}{\eta_m.\eta_g} \tag{5}$$

Burada X_E emisyon faktörünü ve t_{opr} saat cinsinden çalışma süresini ifade eder. Kullanılan dizel yakıt için CO_2 emisyon faktörü 645 g/kWh, NO_X için 12 g/kWh,

SO_2 için 4.1 g/kWh ve HC için 0.2 g/kWh alınmıştır [30].

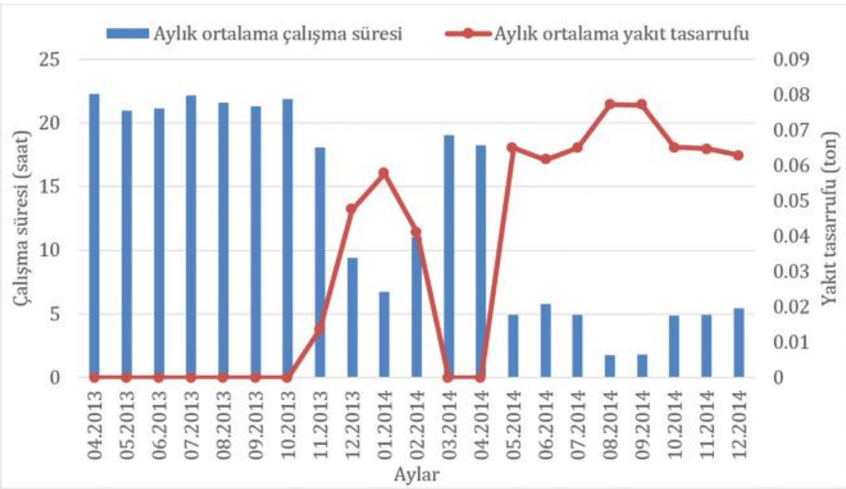
4. Sonuçlar ve Optimizasyon

Yenilenebilir hibrit enerji sisteminin gemiye entegre edilmesiyle jeneratörün elektrik yükü azaltılarak yakıt tasarrufu sağlanmış, dolayısıyla emisyon salınımı da azaltılmıştır. Liman jeneratörünün çalışma süresi azaltılmış ve buna bağlı olarak denklem 4 yardımıyla sağlanan yakıt tasarrufu hesaplanmıştır (Şekil 5).

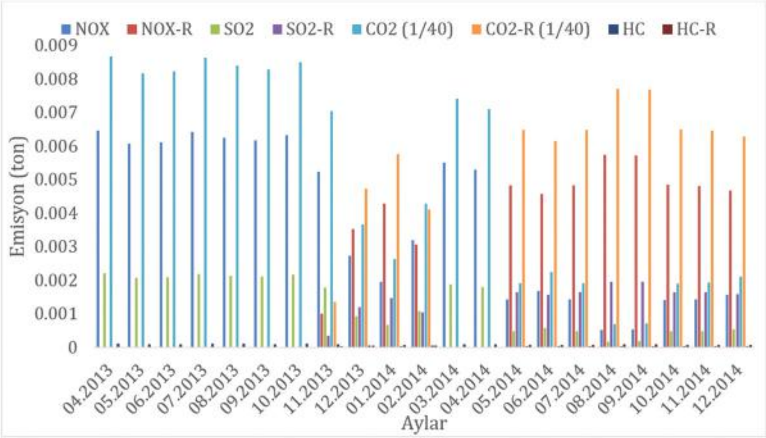
Sistemin 14.11.2013 tarihinde çalıştırılması ile liman jeneratörünün çalışma saatleri düşmeye başlamış, 28.02.2014 - 23.04.2014 tarihleri arasında sistemin arıza yapması sebebiyle kullanılmadığı zamanlarda jeneratör kullanımının tekrar arttığı gözlemlenmiştir. Sistemin kurulduğu tarihe kadar günlük jeneratör çalışma saati ortalaması 21,6 saattir. Sistemin onarılması ve akü ilavesi ile jeneratörün günlük ortalama çalışma saatinin yaklaşık 5 saate indiği görülmektedir. Sistemin kurulmasından sonra çalıştığı süreye bağlı olarak yakıt tasarrufunun arttığı ve Ağustos 2014 ayında yaklaşık 2.25 ton yakıtın tasarruf edildiği görülmektedir.

Yenilenebilir sistemin montajı ile liman jeneratörünün çalışma saati azaltılarak sağlanan yakıt tasarrufu, emisyonların azalmasını da sağlamıştır. Çalışma kapsamında yapılan çevresel etki analizi hesabı, günlük çalışma süreleri üzerinden saatte 5 litre yakıt tüketimi değeri temel alınarak yapılmıştır. Şekil 6'da dizel jeneratörün normal şartlarda yaydığı yaklaşık emisyon miktarları ve yenilenebilir enerji sisteminin entegrasyonuyla denklem 5 yardımı ile hesaplanan, aylara göre sağlanan yakıt tasarrufu değerleri görülmektedir. Grafiklerde emisyon türündeki "R" harfi, sistemin kurulmasıyla salınan emisyon türünü ifade etmektedir. Buna göre, 04.2013 - 12.2014 tarihleri arasında yenilenebilir enerji sistemi olmadan liman jeneratörünün kullanımına devam edildiği durumda günde 21,6 saat çalışma koşuluyla; yaklaşık 3.94 ton NO_X (azot oksit), 1.35 ton SO_2 (kükürt oksit), 211.98 ton CO_2 (karbon dioksit) ve 0.066 ton HC (hidrokarbon) emisyonunun salınacağı hesaplanmıştır.

Yenilenebilir enerji sisteminin devreye alınması ile sistemin arızalı olduğu dönemin de hesaba katıldığı süreçte liman jeneratörünün çalışma süreleri



***Şekil 5.** Liman Jeneratörünün Aylık Ortalama Çalışma Süreleri ve Yakıt Tasarruf Miktarları*



Şekil 6. *Aylara Göre Yayılan Ortalama Emisyon Miktarları*

baz alındığında yaklaşık 1.56 ton NO_X, 0.53 ton $S0_2$, 83.79 ton CO_2 ve 0.026 ton HC emisyonunun atmosfere salınımının engellendiği hesaplanmıştır.

Sistemi oluşturan bileşenlerin güncel fiyatları göz önüne alındığında: inverterin 2.150 USD, rüzgâr türbininin 2.150 USD/adet, güneş panelinin 172 USD/adet, akünün 430 USD/adet, elektrik malzemeleri 1.075 USD, nakliye ve işçiliğin ise yaklaşık 2.150 USD olduğu temel alınarak, kurulum maliyeti 15.179 USD olarak hesaplanmıştır. HOMER programı yardımıyla 64.992 farklı çözüm simüle edilmiştir. Bunların 46.875'inin uygulanabilir olduğu ve 18.117'sinin ise kapasite yetersizliği sebebi ile uygun olmadığı sonucuna varılmıştır. 11.238 çözüm ihmal edilmiştir. Bunların 9.870'i konvertör eksikliği, 180'i gereksiz konvertör ve 1.188'i ise güç üretimi kaynağı sebebiyle ihmal edilmiştir. Tablo 5'te sistemin farklı konfigürasyonlarda ekonomik analizinin sonuçları görülmektedir. Tablo yukarıdan aşağıya, güneş paneli, rüzgâr türbini, jeneratör ve pillerden oluşan konfigürasyonların hesaplanan değerlerini içermektedir. Optimizasyon sonuçlarına göre, bölgede yükü besleyebilecek optimum sistem konfigürasyonunun, 5 güneş paneli, 4 rüzgar türbini, 15 kW'lık bir jeneratör, 32 adet akü (200 AH, 12 V, 2400 W) ve 10 kW'lık bir inverterden oluşan bir sistem olduğu görülmüştür. Optimum konfigürasyona kıyasla kurulan mevcut sistemdeki güneş paneli ve rüzgâr türbini sayıları artırılmalıdır. Fakat gemide bu sistemlerin kurulumu için yeterli alanın olmayışı, optimum konfigürasyonun kullanılmasını sınırlamaktadır. Ayrıca, 15 kW'lık bir jeneratörün, mevcut 35 kW'lık jeneratör ile değiştirilmesi söz konusu değildir ve çalışma saati ciddi oranda azalmakla birlikte mevcut jeneratör çalıştırılmak durumundadır. 25 yıllık kullanım ömrü dikkate alındığında; barca yenilenebilir enerji sistemi kurulmadan önceki durumda, konvansiyel enerji üretim sisteminin net bugünkü maliyeti 726.457 USD olarak hesaplanmıştır. Kurulan yenilenebilir enerji sisteminin net bugünkü maliyeti ise 642.892 USD'dir. Optimizasyon sonuçlarına göre net bugünkü maliyet ise 570.289 USD olmaktadır. Optimum sisteme kıyasla, kurulan sistemin birim enerji maliyeti, işletme maliyeti ve kurulum maliyeti daha fazla olurken, konvansiyonel sisteme kıyasla kurulan sistemin bu maliyetleri daha azdır. Ayrıca kurulan sistemin ortalama geri ödeme süresi 2.04 yıl olarak hesaplanmıştır.

Tablo 5. *Karşılaştırmalı Ekonomik Analiz Sonuçları*

Sistem	COE ($/kWh)	NPC ($)	OC ($/yıl)	IC ($)	PBP (yıl)	RF (%)
Konvansiyonel Sistem	0,714	726.457	55.754	5.700	-	0
Kurulan Sistem	0.632	642.892	46.912	36.434	2.04	0
Optimum Sistem (HOMER)	0,561	570.289	41.432	34.670	1.81	6,24
COE: Birim Enerji Maliyeti, NPC: Mevcut Net Maliyet, OC: İşletme Maliyeti, IC: Kurulum Maliyeti, PBP: Ortalama Geri Ödeme Süresi, RF: Yenilenebilir Enerji Faktörü						

5. Değerlendirme

Bu çalışmada, rüzgâr türbinleri, güneş paneli ve bataryalardan oluşan yenilenebilir bir enerji sisteminin bir yağ barcına uygulanması sonucu yakıt tüketim ve emisyon miktarları hesaplanmış ve sistemin ekonomik analizi ile optimizasyonu HOMER yazılımı ile yapılmıştır. Elde edilen sonuçlara göre;

- HOMER programından alınan veriler doğrultusunda bölgede yaz aylarında güneş yoğunluğunun, bahar ve kış aylarında ise rüzgâr yoğunluğunun arttığı görülmüştür. Dolayısıyla enerji sürekliliğinin sağlandığı görülmüş, bu iki enerji kaynağının ikame şekilde kullanılmasıyla da bölgede sistemin verimli çalışması sağlanmıştır.
- Yenilenebilir enerji sisteminin gemiye entegre edilmesi ile devreye alınması sürecinde ve liman jeneratörünün çalışma koşulları dikkate alındığında yakıt ve emisyonlarda yaklaşık %39 oranında tasarruf sağlanmıştır.
- Ekonomik analiz sonuçlarına göre, kurulan entegre hibrit sistemin geri ödeme süresi 2 yıl gibi kısa bir süreye sahiptir.
- Operasyon süreleri kısıtlı bu tip gemilerde yenilenebilir enerjinin kullanımı, yakıt tasarrufunun sağlanması ve emisyonların azaltılması adına önemli kazanımlar sağlayacaktır.

Gelecek çalışmalar kapsamında, sistemin kurulmasından bu yana, gerçek işletim maliyeti ile çevre etkileri analiz edilecek ve sonuçlar sunulacaktır. Ekonomik analize, şebekeden elektriğin alındığı senaryo da dâhil edilecek ve analiz genişletilecektir.

Teşekkür

Bu çalışmamızda bizlere katkılarını esirgemeyen Prista Holding Türkiye Genel Müdürü Hakan TUNA'ya, Yavuz Deniz Acenteliği Genel Müdürü Yavuz GÜN'e, Erman Enerji Genel Müdürü Erman TANYOLDAŞ'a, Bahri EGE barç kaptanı Mehmet YILDIRAN'a ve değerli personeline teşekkür ederiz.

Kaynaklar

[1] WTO. (2012). International trade statistics. Tech. Rep. Geneva, Switzerland: World Trade Organization.

[2] Mazraati M. (2011). Challenges and prospects of international marine bunker fuels demand. OPEC Energy Rev, 35(1), 1-26.

[3] IMO. (2009). MEPC 59/Inf. 10. Internatıonal Maritime Organization.

[4] IMO. (2014). Third Green House Gas Study. Internatıonal Maritime Organization.

[5] Adaramola, M. S., Agelin-Chaab, M., Paul, S.S. (2014). Analysis of Hybrid Energy Systems for Application in Southern Ghana. Energy Conversion and Management 88 (2014): 284–95.

[6] Bernal-Ag, J., López, D.R. (2009). Simulation and Optimization of Stand-Alone Hybrid Renewable Energy Systems. Renewable and Sustainable Energy Reviews 13 (8): 2111–18.

[7] Askari, I., B., Ameri. M. (2012). Techno-Economic Feasibility Analysis of Stand-Alone Renewable Energy Systems (PV/Bat, Wind/Bat and Hybrid PV/Wind/Bat) in Kerman, Iran. Energy Sources, Part B: Economics, Planning, and Policy 7 (1): 45–60.

[8] Khan, M.R.B., Jidin, R., Pasupuleti, J., Shaaya, S.A. (2015). Optimal Combination of Solar, Wind, Micro-Hydro and Diesel Systems Based on Actual Seasonal Load Profiles for a Resort Island in the South China Sea. Energy 82 (March): 80–97.

[9] Belmili, H., Haddadi, M. Bacha, S., Almi, M.F., Bendib. B. (2014). Sizing Stand-Alone Photovoltaic–wind Hybrid System: Techno-Economic Analysis and Optimization. Renewable and Sustainable Energy Reviews 30 (February): 821–32.

[10] Bhattacharjee, S., Acharya, B. (2015). PV–wind Hybrid Power Option for a Low Wind Topography. Energy Conversion and Management 89 (January): 942–54.

[11] Givler, T. and Lilienthal, P. (2005). Using HOMER®Software, NREL's Micropower Optimization Model to Explore the Role of Gen-Sets in Small Solar Power Systems Case Study : Sri Lanka.

[12] Ismail, M.S., Moghavvemi, M., Mahlia, T.M.I. (2013). Techno-Economic Analysis of an Optimized Photovoltaic and Diesel Generator Hybrid Power System for Remote Houses in a Tropical Climate. Energy Conversion and Management 69 (May): 163–73.

[13] Kaabeche, A., Ibtiouen, R. (2014). Techno-Economic Optimization of Hybrid Photovoltaic/Wind/Diesel/Battery Generation in a Stand-Alone Power System. Solar Energy 103 (May): 171–82.

[14] Kalinci, Y., Hepbasli A., Dincer, I. (2014). Techno-Economic Analysis of a Stand-Alone Hybrid Renewable Energy System with Hydrogen Production and Storage Options. International Journal of Hydrogen Energy, December.

[15] Karakoulidis, K., Mavridis, K. Bandekas, D.V.P. Adoniadis, Potolias, C. Vordos. N. (2011). Techno-Economic Analysis of a Stand-Alone Hybrid Photovoltaic-Diesel–battery-Fuel Cell Power System. Renewable Energy 36 (8): 2238–44.

[16] Lau, K.Y., Yousof, M.F.M. Arshad, S.N.M., Anwari, M., Yatim, A.H.M. (2010). Performance Analysis of Hybrid Photovoltaic/Diesel Energy System under Malaysian Conditions. Energy 35 (8): 3245–55.

[17] Mohamed. H., Amirat, Y. M. Benbouzid, M., Feld, G., Tang, T. and Elbast, A. (2014). Optimal Design of a Stand-Alone Hybrid PV/Fuel Cell Power System for the City of Brest in France To Cite This Version : Optimal Design of a Stand-Alone Hybrid PV/Fuel Cell Power System for the City of Brest in France.

[18] Ramli, M., Hiendro, A., Twaha, S. (2015). Economic Analysis of PV/Diesel Hybrid System with Fl Ywheel Energy Storage. 78: 398–405.

[19] Rehman, S. Al-Hadhrami L. M.. (2010). Study of a Solar PV–diesel–battery Hybrid Power System for a Remotely Located Population near Rafha, Saudi Arabia. Energy 35 (12): 4986–95.

[20] Rohani, G,, Nour, M. (2014). Techno-Economical Analysis of Stand-Alone Hybrid Renewable Power System for Ras Musherib in United Arab Emirates. Energy 64 (January): 828–41.

[21] Kumar, S. U., Manoharan, P.S. (2014). Economic Analysis of Hybrid Power Systems (PV/Diesel) in Different Climatic Zones of Tamil Nadu. Energy Conversion and Management 80 (April): 469–76.

[22] Türkay, B. Telli, E. and Telli, Y. (n.d.). Economic Analysis of Stand Alone and Grid Connected Hybrid Energy Systems, 34–39.

[23] Wen, S., Lan, H., Yu, D., Fu, Q., Hong, Y., Yu, L., and Yang, R., (2017). Optimal sizing of hybrid energy storage sub-system in PV/ diesel ship power system using frequency analysis Energy 140: 198-208.

[24] Alfonsin V., Suarez A., Urrejola S., Miguez J. and Sanchez A. (2015). Integration of several renewable energies for internal combustion engine substitution in a commercial sailboat, International Journal of Hydrogen Energy 40: 6689-6701.

[25] Evrin R.A. ve Dinçer I. (2019). Thermodynamic analysis and assessment of an integrated hydrogen fuel cell system for ships, International Journal of Hydrogen Energy 44: 6919-6928.

[26] Yuan Y., Wang J., Yan X., Li Q. and Long T., (2018). A design and experimental investigation of a large-sacle solar energy/ diesel generator powered hybrid ship, Energy 165: 965-978.

[27] Diab F., Lan H. and Ali S., (2016) Novel comparison study between the hybrid renewable energy system on land and on ship, Renewable and Sustainable Energy Reviews 63: 452-463

[28] Google (t. y.). (Erişim tarihi: 07.05.2019)

[29] Akman, M., Ergin, S. (2018). An investigation of marine waste heat recovery system based on organic Rankine cycle under various engine-operating conditions. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment.

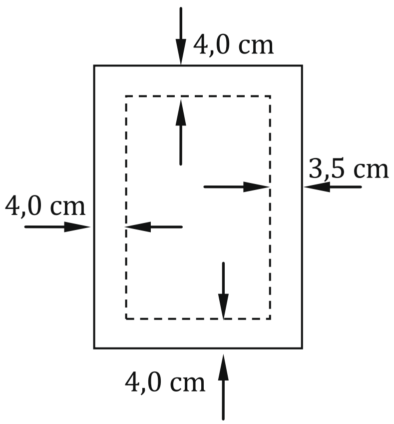
[30] Matel, V., Vladut , G., Mogosan, A., Blaauw, H., Vries, B., Seiwerth, P., Kampfer, A. (n.d.). Emisssion factors in inland navigation.

This Page Intentionally Left Blank

1. JEMS publishes studies conducted in English and Turkish.

2. Text are to be prepared with justified alignment , without indentation in the paragraph beginning, in "cambria" format with 10 point font size and with 1,0 line- spacing. There must be initially 6nk and then 3nk line-spacing between new launching paragraph and previous paragraph. Full text should not exceed 12 pages.

3. Worksheets must be on A4 paper size and margins should be 4 cm from top, 4 cm from bottom, 4 cm from left and 3,5 cm from right.



4. The text of abstract should be written fully justified, in italics and 10 pt. The section should be also no more than 150 words. The number of keywords should be between 3-5.

5. Studies must be submitted online from the journal's web address (http://www.jemsjournal.org). Articles printed or within CD, articles submitted by mail, fax etc. is not acceptable.

1. The main title of article must be written in Turkish and English respectively for Turkish studies, in English for English studies and should be set centered in 12 point-size. Initially 6nk and after 6nk space should be left before the main title.

2. The first letter of the primary headings in the article should be capital letter, and all headings and sub-headings should be designed 10 pt, bold and located to the left with numbering, and also navy blue color should be used for sub-headings.

   1. OrcaFlex Program
   1.1. Axis Team

3. The table heading should be placed above the table and the figure heading should be placed below the figure. 2 nk spaces should be added before the table heading and figure heading and also 3 nk space should be added after. The "table" and the "figure" should be written as bold and left aligned. First letters of table, figure and equation headings should be written with capital letters. The heading and the content should be written with "cambria" font and 10 point size. If tables, figures and equations in the study are cited, their references should be stated. 2 nk spaces should be added before references and 3 nk spaces should be added after. If tables and figures don't fit into a single column, they should be designed to include two columns. Tables and figures which include two columns should be stated at the top or bottom of the page. Total number of figures and tables should not exceed 10.

Table 1. *Sample Table*

Turkish Male Seafarers (n = 131.152)	**BMI < 25,0**	**BMI 25 - 30**	**BMI ≥ 30**	**Number of Participants**
16-24 Ages Group	74,1%	22,5%	3,4%	34.421
25-44 Ages Group	44,1%	43,3%	12,6%	68.038
45-66 Ages Group	25,6%	51,1%	23,4%	28.693
All Turkish Male Seafarers	47,9 %	39,6 %	12,5%	131.152
Turkish Male Population*1	47,3 %	39,0 %	13,7 %	-

1. In the article, decimal fractions should be separated with comma and numbers should be separated with dots.

   Average age: 28,624
   Number of participants: 1.044 people

2. Page numbers, headers and footers should not be added to the study. These adjustments will be made by the journal administration.

3. Authors are deemed to have accepted that they have transferred the copyright of their studies to the journal by submitting their studies to our journal. Submitting a study to two different journals simultaneously is not suitable within the frame of academic ethics.

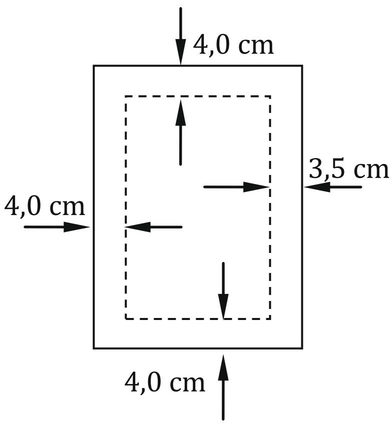
4. It is required that the studies are original and have not been published elsewhere before. If conference and symposium papers were published in a booklet, in this case they shall be published by JEMS on the condition that the copyright has not been transferred to the first publishing place. Information must be given to the journal editorship about the place where these kinds of papers were published before.

5. Citations in the study should be designed in brackets by numbering [1]. References also should be numbered in brackets as well. References should be prepared according to the APA format.

1. JEMS Türkçe ve İngilizce çalışmalar yayımlamaktadır.

2. Hazırlanan metinler; iki yana yaslanmış, paragraf başlarında girinti yapmadan, "cambria" formatında, 10 punto büyüklüğünde ve 1,0 satır aralıklı yazılmalıdır. Yeni başlanan paragraflar ile bir önceki paragraf arasında önce 6nk sonra 3nk satır aralığı olmalıdır. Tam metin toplam sayfa sayısı 12 sayfayı geçmemelidir.

3. Çalışma sayfaları A4 kağıt boyutunda ve üst 4 cm, alt 4 cm, sol 4 cm, sağ 3,5 cm olacak şekilde kenar boşlukları bırakılmalıdır.



4. Öz bölümünde çalışma ile ilgili kısa bilgilere ve temel bulgulara yer verilmelidir. Bu bölüm iki tarafa dayalı, italik ve 10 pt ile yazılmalı ve ayrıca 150 kelimeyi geçmemelidir. Bunun yanında anahtar kelimelerin sayısı ise 3-5 arasında olmalıdır.

5. Çalışmalar derginin web adresinden (http://www.jemsjournal.org) online olarak gönderilmelidir. Basılı ya da CD içerisinde veya posta, faks vb. yollarla gönderilen yazılar kabul edilmemektedir.

6. Makalenin ana başlığı, Türkçe çalışmalarda sırasıyla Türkçe ve İngilizce, İngilizce yazılmış makalelerde ise İngilizce olarak yazılmalı ve 12 punto büyüklüğünde ortalanmış olarak ayarlanmalıdır. Ana başlıktan önce 6nk sonra 6nk boşluk bırakılmalıdır.

7. Makalede yer alan birincil başlıkların ilk harfleri büyük olacak şekilde sola dayalı ve numara verilerek 10 punto ile kalın yazılmalıdır. Alt başlıklar ise aynı şekilde 10 punto ile kalın yazılmalıdır. Bütün başlıklarda ve alt başlıklarda lacivert renk kullanılmalıdır.

    1. OrcaFlex Program
    1.1. Axis Team

8. Tablo başlığı tablonun üstünde şekil başlığı şeklin altında yer almalıdır. Tablo başlığı ve şekil başlığından önce 2 nk sonra 3 nk boşluk bırakılmalı ve sola dayalı olarak sadece "tablo" ve "şekil" yazısı kalın olacak şekilde yazılmalıdır. Tablo, şekil ve denklem başlıklarındaki kelimelerin ilk harfleri büyük yazılmalıdır. Başlık ve içerik "cambria" formatında, 9 punto büyüklüğünde yazılmalıdır. Çalışma içinde yer alan tablo, şekil ve denklemler alıntı yapılmış ise kaynakları belirtilmelidir. Kaynaklardan önce 2 nk sonra 3 nk boşluk bırakılmalıdır. Tablo ve şekiller tek sütuna (burada ki sütun ifadesi makale yazımındakini ifade etmektedir) sığmayacak büyüklükte ise iki sütunu da kapsayacak şekilde verilmelidir. İki sütunu da kapsayan şekil ve tablolara sayfanın en üstünde veya en altında verilmelidir. Toplam şekil ve tablo sayısı 10 adeti geçmemelidir

Tablo 1. *Örnek Tablo*

Turkish Male Seafarers (n = 131.152)	**BMI < 25,0**	**BMI 25 - 30**	**BMI ≥ 30**	**Number of Participants**
16-24 Ages Group	74,1%	22,5%	3,4%	34.421
25-44 Ages Group	44,1%	43,3%	12,6%	68.038
45-66 Ages Group	25,6%	51,1%	23,4%	28.693
All Turkish Male Seafarers	47,9 %	39,6 %	12,5%	131.152
Turkish Male Population*1	47,3 %	39,0 %	13,7 %	-

9. Makale içerisinde ondalık kesirler virgül ile sayılar ise nokta ile ayrılmalıdır.

   Örnek:
   Ortalama yaş: 28,624
   Katılımcı sayısı: 1.044 kişi

10. Çalışmaya sayfa numaraları, alt bilgi ve üst bilgi eklenmemelidir. Bu düzenlemeler dergi yönetimi tarafından yapılacaktır.

11. Yazarlar çalışmalarını dergimize göndererek çalışmalarına ait telif hakkını dergiye devrettiklerini kabul etmiş sayılırlar. Bir çalışmanın aynı anda iki yere birden değerlendirme amaçlı gönderilmesi akademik etik çerçevesinde uygun değildir.

12. Çalışmaların orijinal olması, daha önce başka bir yerde yayımlanmamış olması gerekmektedir. Kongre ve sempozyum bildirileri bir kitapçıkta yayınlanmış ise, bu durumda, telif hakkı ilk yayınlanan yere devredilmemiş olması kaydı ile, JEMS tarafından yayınlanır. Bu tip bildirilerin daha önce yayınlandığı yer ile ilgili dergi editörlüğüne bilgi verilmelidir

13. Çalışma içinde yer alan atıflar parantez içinde numara verilerek yapılmalıdır [1]. Atıflarda olduğu gibi kaynaklar da parantez içinde numaralandırılmalıdır. Kaynaklar APA formatında gösterilmelidir.

Journal of ETA Maritime Science is an independent publication with regards to scientific research and the editor decide its publication policy. The statement signifies the ethical behavior of the publisher, the editor, the reviewers and the authors. The ethics statement for JEMS is based on COPE Code of Conduct and Best Practice Guidelines for Journal Editors and COPE Best Practice Guidelines for Journal Editors available at www.publicationethics.org.

A. DUTIES OF PUBLISHER:

Editorial Autonomy

JEMS is committed to ensure the autonomy of editorial decisions without influence from anyone or commercial partners.

Intellectual Property and Copyright

JEMS protects property and copyright of the articles published in the Journal and maintains each article's published version of record. JEMS provides the integrity and transparency of each published articles.

Scientific Misconduct

JEMS always takes all appropriate measures in respect to fraudulent publication or plagiarism the publisher.

B. DUTIES OF EDITORS:

Decision on Publication and Responsibility

The editor of JEMS keeps under control everything in the journal and strives to meet the needs of readers and authors. The editor also is responsible for deciding which articles submitted to journal ought to be published in the journal, and may be guided by the policies subjected to legal requirements regarding libel, copyright infringement and plagiarism. The editor might discuss with reviewers while making publication decision. Editor is responsible for the contents and overall quality of the publication. Editor ought to provide a fair and appropriate peer-review process.

Objectivity

Articles that submitted to journal are always evaluated without any prejudice.

Confidentiality

Any information about a submitted article must not be disclosed by editor to anyone other than editorial stuff, reviewers, and publisher.

Conflicts of Interest and Disclosure

The Editor of JEMS does not allow any conflicts of interest between the parties such as authors, reviewers and editors. Unpublished materials in a submitted article must not be used by anyone without the express written assent of the author.

C. DUTIES OF REVIEWERS:

Evaluation

Reviewers evaluate manuscripts without origin, gender, sexual orientation or political philosophy of the authors. Reviewers also ensure a fair blind peer review of the submitted manuscripts for evaluation.

Confidentiality

All the information relative to submitted articles is kept confidential. The reviewers must not be discussed with others except if authorized by the editor.

Disclosure and Conflict of Interest

The reviewers have no conflict of interest with regard to parties such as authors, funders, editors and etc.

Contribution to editor

Reviewers give helps the editor in making decisions and may also assist the author in improving the manuscript.

Objectivity

The objective judgment evaluation is always done by them. The reviewers express their views clearly with appropriate supporting arguments.

Acknowledgement of Sources

Reviewers ought to identify relevant published study that has not been cited by the authors. Reviewers also call to the editor's attention any substantial similarity or overlap between the manuscript and any other published paper of which they have personal knowledge.

D. DUTIES OF AUTHORS:

Reporting Standards

A submitted manuscript should be original and the authors ensure that the manuscript has never been published previously in any journal. Data of the research ought to be represented literally in the article. A manuscript ought to include adequate detail and references to allow others to replicate the study.

Originality

The authors who want to submit their study to the journal must ensure that their study entirely original and the words and sentences getting from literature should be appropriately cited.

Multiple Publications

Authors should not submit the same study for publishing any other journals. Simultaneous submission of the same study to more than one journal is unacceptable and constitutes unethical behavior.

Acknowledgment of Sources

Convenient acknowledgment of the study of others has to be given. Authors

ought to cite publications that have been efficient in determining the study. All of the sources that used process of the study should be remarked.

Authorship of a Paper

Authorship of a paper ought to be limited to those who have made a noteworthy contribution to study. If there are others who have participated process of the research, they should be listed as contributors. Authorship also includes a corresponding author who is in communication with editor of a journal. The corresponding author should ensure that all appropriate co-authors are included on a paper.

Disclosure and Conflict of Interest

All sources of financial support should be disclosed. All authors ought to disclose a meaningful conflict of interest in the process of forming their study.

Fundamental Errors in Published Works

If authors find out a remarkable error in their submitted study, they have to instantly inform it. Authors have a liability to cooperate with editor to provide corrections of errors.

ETA Denizcilik Bilimi Dergisi, bilimsel araştırma ile ilgili olarak yayımlanan bağımsız bir yayındır ve yayın politikasını editör belirlemektedir. Bu bildirge dergi imtiyaz sahibi, editör, hakemler ve yazarların etik davranışlarını içermektedir. JEMS'in etik beyanı, COPE Code of Conduct and Best Practice Guidelines for Journal Editors ve COPE Best Practice Guidelines for Journal Editors esaslarına dayanmaktadır ve bu kaynaklar www.publicationethics.org web adresinde ücretsiz olarak paylaşılmaktadır.

A. DERGİ İMTİYAZ SAHİBİNİN SORUMLULUKLARI:

Editoryal Bağımsızlık

JEMS, herhangi bir kimse veya ticari ortaklarının etkisi olmadan editoryal kararların bağımsızlığının sağlanmasını taahhüt etmektedir.

Fikri Mülkiyet ve Telif Hakkı

JEMS, dergide yayımlanan makalelerin mülkiyet ve telif haklarını korur ve her makalenin yayımlanmış versiyonunun kaydını sağlamaktadır. JEMS, yayımlanmış her makalenin bütünlüğünü ve şeffaflığını sağlamaktadır.

Bilimsel Suiistimal

JEMS, hileli yayın veya yayıncı intihali ile ilgili olarak daima uygun tedbirleri almaktadır.

B. EDİTÖRÜN SORUMLULUKLARI:

Yayın ve Sorumluluk Kararı

JEMS editörü, dergideki her şeyi kontrol altında tutmaktadır ve okuyucuların ile yazarların ihtiyaçlarına cevap vermek için çaba göstermektedir. Editör ayrıca,

dergiye gönderilen makalelerden hangilerinin dergide yayınlanacağının ve hangilerinin onur kırıcı yayın, telif hakkı ihlali ve intihal ile ilgili yasal gerekliliklere tabi politikalarla karar verilmesinden sorumludur. Editör, yayın kararı verilirken hakemler ile müzakere edebilir. Editör, içerik ve genel olarak yayın kalitesinden sorumludur. Editör adil ve uygun bir hakem süreci sağlamalıdır.

Tarafsızlık

Dergiye gönderilen makaleler daima, herhangi bir önyargı olmaksızın değerlendirilmektedir.

Gizlilik

Dergiye gönderilen bir makale ile ilgili herhangi bir bilgi, editör tarafından yayın kurulu, hakemler ve dergi sahibi dışında herhangi bir kimseye ifşa edilmemelidir.

Çıkar Çatışmaları ve İfşa Etme

JEMS editörü yazarlar, hakemler ve editörler gibi taraflar arasındaki herhangi çıkar çatışmalarına izin vermez. Dergiye gönderilen bir makaledeki yayınlanmamış materyaller, yazarın sarih bir yazılı onayı olmadan herhangi biri tarafından kullanılmamalıdır.

C. HAKEMLERİN SORUMLULUKLARI:

Değerlendirme

Hakemler yazarların kökeni, cinsiyeti, cinsel eğilimi veya siyasal felsefesine bakılmaksızın eserleri değerlendirmektedirler. Hakemler ayrıca, dergiye gönderilen metinlerin değerlendirilmesi için adil bir kör hakemlik süreci sağlamaktadırlar.

Gizlilik

Dergiye gönderilen makalelere ilişkin tüm bilgiler gizli tutulmaktadır. Hakemler, editör tarafından yetkilendirilmiş olanlar dışında başkaları müzakere etmemelidir.

İfşa Etme ve Çıkar Çatışması

Hakemlerin; yazarlar, fon sağlayıcılar, editörler vb. gibi taraflar ile menfaat çatışması bulunmamaktadır.

Editöre Destek

Hakemler, karar verme aşamasında editörlere yardım ederler ve ayrıca metinlerin iyileştirilmesinde yazarlara yardımcı olabilmektedirler.

Tarafsızlık

Objektif bir karar değerlendirmesi, daima hakemler tarafından yapılmaktadır. Hakemler, uygun destekleyici iddialarla, açık bir şekilde görüşlerini ifade etmektedirler.

Kaynakların Referansı

Hakemler ayrıca, kendi bilgileri dahilindeki yayınlanmış diğer herhangi bir makale ile dergiye gönderilen metin arasında herhangi önemli bir benzerlik veya örtüşme ile ilgili olarak editörü bilgilendirmelidir.

D. YAZARLARIN SORUMLULUKLARI:

Bildirme Standartları

Dergiye gönderilen bir metin özgün olmalıdır ve yazarlar, metnin daha önce herhangi bir dergide yayınlanmamış olmasını sağlamalıdırlar. Araştırmanın verileri, makalede tam olarak belirtilmelidir. Dergiye gönderilen bir metin, başkalarının çalışmayı türetmesine izin vermek üzere yeterli detay ve referansları içermelidir.

Özgünlük

Çalışmalarını dergiye göndermek isteyen yazarlar, çalışmalarının tamamen özgün olmasını sağlamalıdır ve literatürden elde edilen kelimeler ile cümleler uygun bir şekilde alıntılanmalıdır.

Birden Fazla Yerde Yayın

Yazarlar, aynı çalışmayı herhangi bir başka dergide yayınlanmak üzere göndermemelidirler. Aynı çalışmanın birden fazla dergiye eş zamanlı gönderilmesi etik olmayan bir davranış teşkil etmektedir ve kabul edilemez.

Kaynakların Referansı

Başkalarının çalışmalarıyla ilgili olarak uygun referanslar verilmelidir. Yazarlar, çalışmalarının belirlenmesinde etkili olmuş yayınlara referans vermelidirler. Çalışma sürecinde kullanılan kaynakların tümü belirtilmelidir.

Makale Yazarlığı

Makale yazarlığı, çalışmaya kayda değer katkıda bulunan kişilerle sınırlı olmalıdır. Araştırma sürecine katılan başkaları var ise, bu kişiler katkıda bulunanlar olanlar listelenmelidir. Yazarlık ayrıca, derginin editörü ile iletişim halinde olan yazışmadan sorumlu olan bir yazar içermelidir. Yazışmadan sorumlu yazar, tüm yardımcı yazarların makaleye dahil olmasını sağlamalıdır.

İfşa Etme ve Çıkar Çatışması

Finansal destek ile ilgili tüm kaynaklar açıklanmalıdır. Tüm yazarlar, çalışmalarının oluşturulması sürecinde yer alan çıkar çatışmasını ortaya koymalıdırlar.

Yayınlanmış Çalışmalardaki Temel Hatalar

Yazarlar göndermiş oldukları çalışmalarında dikkat çekici bir hata bulduklarında, bu hata ile ilgili olarak derhal dergiyi bilgilendirmek zorundadırlar. Yazarların, hataların düzeltilmesini sağlamak üzere editör ile birlikte çalışma yükümlülükleri vardır.

Reviewer List of Volume 7 Issue 2 (2019)

Abit BALİN	İstanbul University	Turkey
Adnan KEFAL	Sabancı University	Turkey
Alper KILIÇ	Bandırma Onyedi Eylül University	Turkey
Asım Sinan KARAKURT	Yıldız Technical University	Turkey
Aykut SAFA	Yıldız Technical University	Turkey
Aylin ÇALIŞKAN	Yaşar University	Turkey
Batuhan AKTAŞ	University of Strathclyde	UK
Bozo VAZIC	University of Strathclyde	UK
Emre AKYÜZ	Bursa Technical University	Turkey
Fahri ÇELİK	Yıldız Technical University	Turkey
Gülsen YAMAN	Balıkesir University	Turkey
Gökçe Çiçek CEYHUN	Kocaeli University	Turkey
Gökhan ÖZÇELİK	Karadeniz Technical University	Turkey
Hasan Kayhan KAYADELEN	Yıldız Technical University	Turkey
Hüseyin Avni ES	Karadeniz Technical University	Turkey
Kadir ÇİÇEK	İstanbul Technical University	Turkey
Levent BİLGİLİ	Bandırma Onyedi Eylül University	Turkey
Lütfullah KUDDUSİ	İskenderun Technical University	Turkey
Mehmet KAPTAN	Recep Tayyip Erdoğan University	Turkey
Muhammet GÜL	Munzur University	Turkey
Olgun Güven HIZIR	University of Strathclyde	UK
Osman Azmi ÖZSOYSAL	İstanbul Technical University	Turkey
Özgür KABAK	İstanbul Technical University	Turkey
Sadık Özlen BAŞER	Dokuz Eylül University	Turkey
Seçil VARAN	Dokuz Eylül University	Turkey
Selma ERGİN	İstanbul Technical University	Turkey
Sercan EROL	Karadeniz Technical University	Turkey
Serkan TÜRKMEN	Newcastle University	UK
Ünal ÖZDEMİR	Mersin University	Turkey
Veysel TATAR	Artvin Çoruh University	Turkey

Volume 7 Issue 2 (2019) is indexed in

DOAJ DIRECTORY OF OPEN ACCESS JOURNALS

OAJI .net Open Academic Journals Index

TÜBİTAK ULAKBİM

I2OR

INDEX COPERNICUS INTERNATIONAL

Academic Resource Index ResearchBib

İNFOBASE INDEX

CiteFactor Academic Scientific Journals

SIS Scientific Indexing Services


Exceptional Craftsmanship
Excellent Engineering
Exclusive Tugboats
CLAUS
RAmparts 3200 / 3275 ASD TUG
MED MARINE
SINCE 1995
SEA THE FUTURE...
HEAD OFFICE
MED MARINE
Ömer Avni Mah. Inebolu Sok. No:21, 34427
Setüstü-Kabataş, Beyoğlu-İstanbul / TURKEY
Phone : +90 212 311 18 00
Fax : +90 212 252 16 80
E-mail : info@medmarine.com.tr
Web : www.medmarine.com.tr
/medmarine
/medmarine_
Med Marine
SHIPYARD
EREĞLİ SHIPYARD
Gülüç Çengelburnu Karadeniz Ereğli,
Zonguldak/ TURKEY
Phone : +90 372 318 27 40
Fax : +90 372 318 27 42
E-mail : info@ereglishipyard.com.tr
Web : www.ereglishipyard.com
/ereglishipyard
Ereğli Shipyard


UZMAR®
7 / 24
30 PILOT CAPTAINS
350 TEAM MEMBERS
29 VESSELS
MAXIMUM EFFICIENCY
ZERO RISK
ONE VISION
SAFETY FIRST
SINCE 1973
www.uzmar.com.tr - izmir@uzmar.net

This Page Intentionally Left Blank

Journal of ETA Maritime Science
Volume 7, Issue 2, (2019)

Contents

UCTEA - The Chamber of Marine Engineers