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RESEARCH ARTICLE

ON THE SELECTION OF SHIP WASTEWATER TREATMENT PLANT INCORPORATING ANALYTICAL HIERARCHY PROCESS WITH 0-1 GOAL PROGRAMMING

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ABSTRACT

As a result of the continuous pollution of the air, seas and soil, the deterioration of the natural equilibrium can be felt severely. Therefore, the prevailing vision of sustainable environment is frequently mentioned in the international arena. There are many industrial sources of pollution. Each of them significantly affects the environment. In the seas, the biggest source of pollution is the ships. Pollutants originating from ships are solid pollutants, bilge water, ballast water, anti-fouling system, etc. Another important source of pollution is wastewater. Untreated wastewater discharged to the sea will cause the natural balance to deteriorate. Therefore, wastewater treatment equipment is needed. The integration of equipment in ship design is a challenging process and many criteria must be considered together. In this study, it is stated that the criteria of the ship wastewater system will be evaluated and a set of alternatives is determined by Analytical Hierarchy Process (AHP). In addition, in accordance with a scenario created by considering the integration constraints of these systems into the ship, a hybrid model in which the 0-1 Goal Programming and AHP weights are applied, and the optimum solution (equipment) is selected which satisfies the determined constraints.

Keywords: *Ship Wastewater Treatment Plant, Multi-Criteria Decision Making (MCDM), Analytical Hierarchy Process (AHP), 0-1 Goal Programming.*

ANALİTİK HİYERARŞİ SÜRECİ VE 0-1 HEDEF PROGRAMLAMA YÖNTEMİ İLE GEMİ PİS SU ARITMA ÜNİTESİ SEÇİMİ

ÖZ

Havanın, denizlerin ve toprağın sürekli kirletilmesi neticesinde doğal dengenin bozulması şiddetli bir şekilde hissedilir duruma gelmektedir. Bu nedenle, günümüzde sürdürülebilir çevre anlayışının hakim kılınması, ulusal ve uluslararası arenada sıkça belirtilmektedir. Endüstriyel kaynaklı birçok kirlilik kaynağı mevcuttur. Her biri çevreyi önemli ölçüde etkilemektedir. Denizlerde ise bu kirliliğinin en büyük kaynağı gemilerdir. Gemilerden kaynaklı katı kirleticiler, sintine suları, balast suları, yosun-tutmaz sistemlerden kaynaklı kirleticiler buna örnek gösterilebilir. Bir diğer önemli kirlilik kaynağı ise gemilerde üretilen atık sulardır. İşlem görmeden denizlere salınması halinde doğal dengenin bozulmasına sebebiyet verecektir. Bu nedenle atık suyu işlemden geçirecek ekipmanlara ihtiyaç duyulmaktadır. Gemi dizaynında bir ekipmanın entegre edilmesi oldukça zorlu bir süreçtir ve bir çok kriterin birlikte değerlendirilmesi gerekmektedir. Bu çalışmada bir atık su sisteminin hangi kriterler çerçevesinde değerlendirileceği ortaya konmakta ve belirlenen alternatiflerden hangisinin seçileceği Analitik Hiyerarşi Süreci (AHS) ile belirlenmektedir. Ayrıca, bu sistemlerin gemiye entegrasyonunda yaşanan kısıtlar göz önüne alınarak yaratılan bir senaryoya uygun olarak 0-1 Hedef Programlama ve AHS ağırlıklarının uygulandığı hibrit bir model ortaya konulmakta, ve belirlenen kısıtları sağlayan optimum çözüm (ekipman) seçilmektedir.

Anahtar Kelime: *Gemi Atık Su Arıtma Ünitesi, Çok Kriterli Karar Verme (ÇKKV), Analitik Hiyerarşi Süreci(AHS), 0-1 Hedef Programlama*

1. INTRODUCTION

Leaving all kinds of waste to nature and the effects of these waste on the nature are defined as pollution [1]. Even though the rapid development of science and technology in the world has a very positive contribution to human life, the pollution caused by people against nature is constantly increasing. A continuous production, and consequently a continuous consumption, as well as the fact that a sustainable environmental consciousness cannot be taken socially, causes nature to be adversely affected. As the environmental pollution started to affect the life, the importance of pollution has prevented the convenience of technology. However, individuals, societies, governments, and even global organizations are taking very important steps in order to prevent the adverse effects of environmental pollution. Even small steps are taken seriously for environmental sustainability such as going paperless in formal corresponding [2]. Pollution occurs on land, sea and air. The space debris formed by satellite and space shuttles can be added to this definition. As part of the scope of this study, marine pollution will be discussed later.

71% of the earth's surface is covered with water and 96.5% of this water is in the oceans [3]. Other water sources include groundwater, lakes, rivers, etc. The journey of all wastes on the earth ends in seas and oceans and this pollution is caused by 4 main elements [1]:

- **Land Based (44%):** Pollutants from land to oceans or seas are mostly caused by rivers. The biggest threat from the land is plastic and sewage systems.
- **Air Based (33%):** Dust from the desert is one of the major pollutants in the sea. In addition, acid rain from air pollution significantly affects the pollution of the seas.
- **Maritime Activities and Accidents (12 % + 10%):** Especially, pollution caused by tanker accidents has a negative impact on the seas for decades. Apart from this, sewage waste, solid waste, bilge waste, gas waste from exhaust emission, ballast-borne waste affecting biological equilibrium are considered as maritime activity pollution.
- **Offshore Mining and Drilling (1%):** Pollution due to the drilling of the seabed.

1.1. Ship borne Pollution

The pollution caused by Maritime activity is ranked 3rd according to the total pollution in nature and the main reason for this pollution is the ships. According to United Nations Convention on the Law of the Sea, pollution of the marine environment means "the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities" [4].

World trade, with the increasing world population, is constantly increasing in both volume and value. According to World Trade Organization, in 2017, there is a growth of 11% in value and 4.7% in volume in world trade [5]. In addition, global sea trade realized a growth of 4% in 2017 and it is estimated that this growth will be 3.8% compound annual growth rate (CAGR) between 2018-2023 [6]. In addition, the biggest side effect of the growth of the sea trade volume is the increase in the number of ships and the tonnage. This growth is also 3.3% in 2017 [6]. When the ship numbers are considered, this growth is 14.5% between 2011-2018 [7]. As can be seen from this point, the sea transportation fleet has achieved a lot of growth. Therefore, it is considered that this growth will have adverse effects on marine pollution.

With the growth of world trade and the fact that maritime transport has a significant role in this trade volume, the increase in the number of ships comes into prominence. The negative impacts of each ship on the environment are undeniable. Because, there are many types of pollutants released from the ships. To group these pollutants as in Figure 1 [1, 8, 9]:

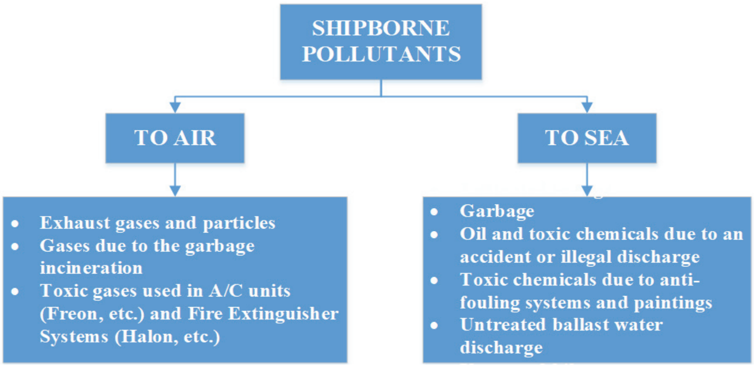

Figure 1. Ship borne Pollutants.

1.2. Wastewater as a Ship borne Pollutant

The diversity of marine pollution is determined to be very high according to Figure 1, however preventive and corrective measures are taken by international organizations and governments for each of these pollutants. In this study, a detailed review of all these pollutants is considered outside the scope, and each topic needs to be evaluated as a separate research area. Therefore, the scope of this study is narrowed as seaborne wastewater.

According to MARPOL 73/78 (Annex IV) [10], sewage refers to:

- Waste from toilets, urinals and WC scupper,
- Drains (wash basin, wash tub, scuppers, etc.) from medical facilities,
- Drains from places in which animal habitat,
- All other drains in a contact with above waste definitions.

In addition, the wastewater is considered in two categories as grey water and black water and their contents are represented by Figure 2. Disposal of the waste mentioned in both section without treatment is prohibited to some extend by national and international regulations.

- **Greywater:** The impact of greywater on pollution of the seas is not as high as other wastes. However, it can be harmful because it contains high bacteria and chemicals, and pollutes the water if it is discharged untreated [11].

- **Black Water:** It is an important source of pollution in the sea. Because it contains high amounts of bacteria and viruses, it can affect both sea creatures and people who consume them. It also causes the spread of diseases in direct contact with people [12].

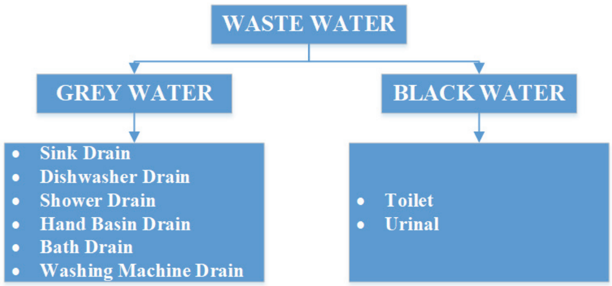

Figure 2. Wastewater Definition.

As a result of international regulations, these wastes can be discharged into the sea by treating them and providing certain conditions, especially as specified in MARPOL. The reference values are provided by IMO Resolution MEPC.159 (55) to ensure that these wastes can be discharged into the sea, and only under these conditions, discharge can take place (IMO MEPC 55/23-ANNEX 26, 2006) [13]. In order to treat these wastes, it is necessary to have a Marine Wastewater Treatment Plant capable of fulfilling the IMO regulations and the ships must receive the International Sewage Pollution Prevention Certificate. Waste treatment is carried out in 3 basic ways: 1) mechanical, 2) chemical, 3) biological. The treatment of waste is provided by hybrid models of these three processes. Therefore, the working principle of wastewater treatment plant can be described as: 1) mechanical-chemical, 2) mechanical-biological, 3) chemical-biological [14].

With the increase in sea trade and the number of ships, it will be inevitable that sea pollution will increase at the same rate. The national and international measures taken in this context with all the details include the issues to be done at the design stage of the ships. In particular, MARPOL 73/78 contains a number of important measures related to ship-borne pollutants. These measures are essential to implement in the ship design from the very beginning, and the selection of suitable equipment and devices for the treatment of pollutants is a prerequisite. The most important challenge faced by the ship design engineers is to make the optimum technical decision while applying the regulations effectively. Therefore, the placement of equipment in ship design is very important. Designers spend a great amount of time and effort to place a lot of equipment items in a very limited space and to integrate them in the optimal way. Many criteria need to be considered together, and if there are more than 30 equipment items in a machine room, the solution to this situation is almost impossible.

The motivation of this study, as mentioned above, is to look for the answer to the question of how to implement the measures and rules in the protection of the seas and the environment with seriousness and how to ensure the technical requirements of equipment selection in ship design and how to integrate an equipment item. In this context, a literature review is carried out in Section 2 for the purpose of equipment selection. As seen in the literature, the equipment selection study is generally evaluated in terms of land facilities and MCDM methods are used extensively. In Section 3, the research problem is defined and the evaluation criteria of the problem are presented. In Section 4, AHP and 0-1 Goal Programming methods are applied in order to solve the problem. The results of the study are discussed in Section 5.

2. LITERATURE REVIEW

Selection of an equipment is considered as a Multi Criteria/Objective Decision Making (MCDM) problem. A proper selection of an equipment is a crucial issue for any decision maker since it is directly related to both financial and technical aspects. Selection of an improper equipment causes serious problems for a company, factory etc. in terms of efficiency and productivity [15]. In literature, there is numerous studies regarding equipment selection among many alternatives. Dağdeviren [15] proposed AHP-PROMETHEE integrated approach for milling machine selection. The criteria used for selection are price, weight, power, spindle, diameter and stroke. Tuzkaya et.al. [16] utilized F-ANP and F-PROMETHEE for material handling equipment selection and considered criteria such as power and space requirements, reliability, maintainability, adaptability, operational flexibility, power usage, etc. Lashgari et.al. [17] also proposed an integrated MCDM method of F-AHP, F-ANP and F-TOPSIS for loading equipment in mining industry. Some of the technical criteria for selection problem are maintenance, flexibility, availability, production rate, power, etc. Demirel [18] presents ship roll motion stabilizing system selection with hybrid F-AHP and F-TOPSIS methods. Demirel et.al. [19] utilized F-AHP and Electre for selecting ship stabilizing device. When the literature is reviewed there are such studies which discuss equipment selection in various purposes with MCDM techniques as well as roll stabilizer selection for ships are presented in some studies. However, the missing point in which, researchers omit that the integration of equipment on board have certain constraints. All the constraints are required to be evaluated together with a multi-objective optimization perspective. The literature possesses a gap for ship auxiliary system selection under constraints for fulfilling multiple objectives.

3. PROBLEM DEFINITION

In this study, wastewater treatment plants will be evaluated with a purely technical and design perspective and the criteria related to their integration into the ship will be laid down. In the equipment selection literature, maintenance and availability terms are affiliated with technical perspective [16, 17] and we refer them as ease of operation. Adaptability and flexibility terms where we referred to ease of integration, and power, space, weight, capacity terms are also mentioned in the literature [15, 16, 17]. The grounded criteria and the definitions for the evaluation of Wastewater Treatment Plant are shown in the Table 1.

Table 1. Wastewater Treatment Plant Selection Criteria in a Technical and Design Aspect

Number of Criteria	Criteria	Definition of the Criteria
1	Ease of Operation	When it is considered that an equipment item will be used throughout the life-cycle of the ship, it is very important for designers to choose a system that is the easiest to use, with a long maintenance period and a simple working principle.

2	Ease of Integration	An important factor in choosing a system in ship design is easy integration. The need for complex integration with other systems, quite a lot of piping, the need for extra tank and equipment, etc. create quite a problem in terms of integration and, adaptability and flexibility are sought for integration.
3	Volume Requirement	The volume occupied by an equipment item is a critical requirement for a ship. The smaller the volume used, the higher the volume that can be allocated for cargo needs, and this will result in a huge gain considering the impact of the ship on a projection through the life cycle.
4	Weight	Weight is a very important criterion when it is evaluated that hundreds of equipment are used on a ship. Each added extra weight is a resistance gain and has a significant impact on fuel consumption.
5	Capacity	It is an important criterion to choose an equipment item which provides a capacity requirement according to the amount of daily wastewater produced by an individual specified by international regulations. Otherwise, it is quite costly to bear the wastewater transfer fee to be used at the ports due to equipment that does not have sufficient treatment capacity.
6	Power Requirement	As a result of the electrical load required by each equipment item, the total load is determined and the corresponding diesel-generator set is determined. In this context, it is targeted to have a minimum level of power requirement for each equipment item.

These criteria are determined through literature review and Delphi Method together with a group of experts whose profiles are given with Table 2. DM group consists of highly knowledgeable and experienced engineers in ship design. Two meetings were held with DM group to determine related criteria for evaluation of wastewater treatment plant selection.

Table 2. Profiles of Decision Makers

# of Participant	Position	Experience (years)	Graduate Degree
1	Design Engineer (Mechanical Eng.)	18	Ph.D.
2	Design Engineer (Mechanical Eng.)	4	M.S.
3	Design Engineer (Mechanical Eng.)	5	M.S.
4	Design Engineer (Mechanical Eng.)	2	B.S.

4. SOLUTION APPROACH

The weights of the determined criteria and the importance weights of the candidate equipment to be selected is determined by the Analytic Hierarchy Process (AHP). A case scenario equipment integration problem is created and constraints are elaborated. Together with AHP results and constraints, 0-1 Goal Programming approach is implemented to select the optimum equipment.

4.1. Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a MCDM method developed by Thomas L. Saaty, which takes a practical and easy approach for solving many problems [20]. It identifies a problem in a hierarchical way, separates it into criteria and sub-criteria, and then synthesizes these criteria, thus weights the criteria or alternatives. AHP method is widely used in literature for weighting criteria and selection among alternatives [21, 22, 23]. AHP method has the following steps.

- **Problem Definition and Goal Statement:** Wastewater Treatment Plant selection is shown in Figure 3 in a hierarchical way. Main objective is shown on the top side of the AHP presentation and evaluation criteria are given that all the criteria are in an interaction with alternatives where the bottom of the hierarchy.

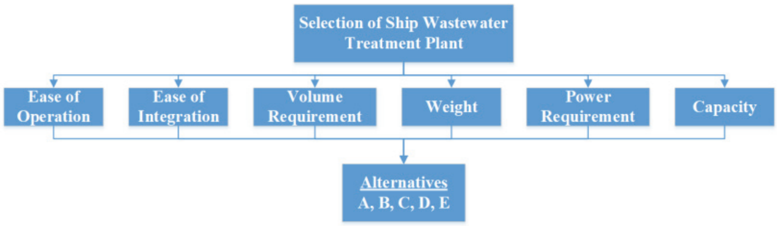

Figure 3. AHP Problem Definition.

- **Listing Decision Criteria and Alternatives:** Decision criteria are given in Table 1 and Alternatives are given in Table 3. Make and model of the equipment are not disclosed because of the confidentiality and will be represented as “A,B,C,D and E”.

Table 3. Ship Wastewater Treatment Plant Alternatives

	Treatment Process Type	Capacity (m3/day)	Length (mm)	Width (mm)	Height (mm)	Full Weight (kg)	Energy Consumption (kW)
A	Biological	7.4	2970	1870	2295	7700	12.75
B	Biological	7.4	3510	1650	1570	7300	7.4
C	Biological	7.0	3000	1500	2000	7800	5.7
D	Biological	8.7	4701	2200	2096	14130	4.2
E	Biological	9.36	3072	2280	1971	7367	6.4

- **Creation of Pairwise Comparison Matrix for criteria and alternatives and obtaining priority vector:** Pair-wise comparisons of the alternatives are done with the same expert group whose profiles are given in Table 2. AHP questionnaire containing the evaluation of both criteria and alternatives were handed out to each decision maker. Thus, comparison matrices are given in Appendix.

Results of the criteria comparison by using AHP method are shown with Table 4.

Table 4. Priority Weight of the Criteria.

Criteria	Priority Weight
Ease of Operation	0.072
Ease of Integration	0.043
Volume Requirement	0.209
Weight	0.075
Capacity	0.526
Power Requirement	0.075
Consistency Ratio	0.097

Results of the alternative comparison by using AHP method are shown with Table 5.

Table 5. Priority Weight of the Alternatives.

ALT.	Ease of Operation	Ease of Integration	Vol. Req.	Weight	Cap.	Power Req.	Alternative Priority Weight
A	0.15	0.181	0.141	0.18	0.14	0.033	0.138—5
B	0.355	0.295	0.363	0.308	0.137	0.073	0.215—2
C	0.136	0.139	0.402	0.177	0.098	0.235	0.182—4
D	0.141	0.157	0.032	0.024	0.24	0.542	0.192—3
E	0.218	0.228	0.062	0.311	0.385	0.117	0.273—1
CR	0.0945	0.0259	0.080	0.012	0.016	0.088	

As seen from Table 4. and 5, the most important criteria is Capacity, and Volume Requirement, Power Requirement, Weight, Ease of Operation, Ease of Integration from highest to the lowest important. Besides, last column of Table 5 shows that alternatives from most appropriate to the least are E, B, D, C, A. In addition, AHP results are consistent since CR is less than 0.1. As seen from the analysis, capacity is the most important criterion with a great impact in decision making. Performance is the top priority in an equipment selection problem. As for a wastewater treatment plant, the lower capacity yields to a design problem.

4.2. Goal Programming

Multi criteria decision making methods are widely in use in selection or ranking problems with less information, however MCDM does not produce solutions when resources are of vital importance. In today's complex decision making environment, managers have to deal with many conflicts of interest with uncertainty. Therefore, goal programming (GP) is proposed to take into account multiple criteria (conflict of interest) for decision making problems [24]. Goal programming is a linear programming approach created to solve multiple objectives. In GP, beyond the purpose of minimization or maximization of one goal, it is attempted to obtain a minimum deviation from which each of the goals can be compromised. Each variable constituting the objective function must have the same unit in linear programming, while we attempt to obtain the sum of deviations in goal programming and calculate the minimum deviation to provide multiple targets with different units. Objective function reflects the minimization of deviations from the desired objectives and constraints represents the resource availability. Thus, the selection problem formulated as Goal Programming since it is attributed to be more powerful than linear programing [24].

4.3. Incorporating AHP into 0-1 Goal Programming

0-1 Goal Programming and AHP methods are commonly used to solve selection problems such as; supplier selection problem is addressed by Dağdeviren and Eren [25], selection of an advertisement strategy is addressed by Alagas et.al. [26], software selection problem is addressed by Girginer and Kaygısız [27], and maintenance selection problem is addressed by Bertolini and Bevilacqua [28]. Although it is quite simple and straightforward to use, AHP has a certain limitation since it only depends on the intuition of decision maker. However, combination of AHP and Goal Programming improves the solution since it takes into account the constraints.

The general description of hybrid AHP and 0-1 Goal programming objective function can be interpreted as shown in Equation 1 [29, 30].

$$\text{Min Z} = \sum_{k=1}^{K} (w_k d_k^-, w_k d_k^+)$$

is subject to,

$$\left[\sum_{i=1}^{m} (a_{ki} x_k)\right] + d_k^- - d_k^+ = b_k$$

with i=1,2,…m (number of constraints), (1)

$d_k^- . d_k^+ = 0$,

$x_k = \begin{cases} 1 \\ 0 \end{cases}$,

$x_k, d_k^-, d_k^+ \geq 0$,

where,

w_k	Priority weight of the kth goal
d_k^-, d_k^+	Negative and positive deviation from the kth goal
a_{ki}	Coefficients of ith constraint in kth goal
x_k	Decision variables:

$$x_k = \begin{cases} 1, & k^{th} equipment\ selected \\ 0, & otherwise \end{cases}$$

b_k	Goal level (resources)

Decision constraints for selection problem are considered to be length (C1), width (C2), height (C3), weight (C4), power requirement (C5), capacity of the equipment (C6) and AHP weights (C7). The design engineer identifies the design constraints in order to select the most suitable Wastewater Treatment Plant for use on a ship with 50 personnel by minimizing the total deviation as:

- C(1): Length of the equipment is to be less than 3000 mm,
- C(2): Width of the equipment is to be less than 1900 mm,
- C(3): Height of the equipment is to be less than 2000 mm,

- C(4): Weight of the equipment is to be less than 8000 kg,
- C(5): Power requirement of the equipment is to be less than 6 kW,
- C(6): Capacity of the equipment is to be more than 6.75 m^3/day,
- C(7): AHP Constraint.

Thus, 0-1 goal programming problem with AHP can be defined as in Girginer and Kaygısız [27] and shown with Equation 2:

Obj Func. $\text{Min } Z = d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+ + d_6^- + d_7^+ + d_7^-$
Subject to

C(1) $2970 * x_1 + 3510 * x_2 + 3000 * x_3 + 4701 * x_4 + 3072 * x_5 + d_1^- - d_1^+ = 3000$

C(2) $1870 * x_1 + 1650 * x_2 + 1500 * x_3 + 2200 * x_4 + 2280 * x_5 + d_2^- - d_2^+ = 1900$

C(3) $2295 * x_1 + 1570 * x_2 + 2000 * x_3 + 2096 * x_4 + 1971 * x_5 + d_3^- - d_3^+ = 2000$

C(4) $7700 * x_1 + 7300 * x_2 + 7800 * x_3 + 14130 * x_4 + 7367 * x_5 + d_4^- - d_4^+ = 8000$ (2)

C(5) $12.75 * x_1 + 7.4 * x_2 + 5.7 * x_3 + 4.2 * x_4 + 6.2 * x_5 + d_5^- - d_5^+ = 6$

C(6) $7.4 * x_1 + 7.4 * x_2 + 7 * x_3 + 8.7 * x_4 + 9.36 * x_5 + d_6^- - d_6^+ = 6.75$

C(7) $0.138 * x_1 + 0.215 * x_2 + 0.182 * x_3 + 0.192 * x_4 + 0.273 * x_5 + d_7^- - d_7^+ = 1$

C(8) $x_i = 0 \text{ or } 1;\ i = 1,2,3,4,5$

$$x_i = \begin{cases} 1, & i^{th} \text{ equipment selected} \\ 0, & \text{otherwise} \end{cases}$$

C(9) $d_j^-, d_j^+ \geq 0;\ j = 1,2,3,4,5,6,7$

When the coefficients of Goal-2 are carefully evaluated, it will be seen that there are very large differences (for example, 7700 in C (4) and 7.4 in C (6)). This constitutes a bias in favor of large coefficients, and the goals with large coefficients become more important. In order to overcome this deficiency, the normalization process specified by Romero [31] is applied. In this context, deviational variables of Objective Function in Equation 2 are required to be revisited as shown in Equation 3:

$$(d_j^-)' = \frac{d_j^-}{\left(\sum_{j=1}^{7}(a_{ji})^2\right)^{1/2}} \qquad (d_j^+)' = \frac{d_j^+}{\left(\sum_{j=1}^{7}(a_{ji})^2\right)^{1/2}} \tag{3}$$

Therefore, weighted objective function is given as in Equation 4:

$$Min\ z = \left(\frac{d_1^+}{(2970^2 + 3510^2 + 3000^2 + 4701^2 + 3072^2)^{1/2}}\right) + (d_2^+)' + (d_3^+)' + (d_4^+)' + (d_5^+)' + (d_6^-)' + (d_7^+)' + (d_7^-)' \tag{4}$$

The solution of the Equation 4 yields to Table 6 which gives decision variables (x_1, x_2, x_3, x_4, x_5) and deviation variables ($d_1,\ldots,d_7$).

Table 6. Results of 0-1 Goal Programming

Decision Variable	x_1	x_2	x_3	x_4	x_5	$(d_1^+)'$	$(d_2^+)'$	$(d_3^+)'$	$(d_4^-)'$	$(d_5^+)'$	$(d_6^+)'$	$(d_7^-)'$	$(d_7^+)'$
WGP Solution	0	0	0	0	1	72	380	29	633	0.2	2.61	0.727	0

Alternative "E" reflects the minimum total deviation with 0.17. Deviation variables, $d_1^+, d_2^+, d_5^+, d_6^+$, represent that the criterion for the selected equipment is more than the desired goal. This is not the targeted result since constraint 1 to 5 force to select an alternative to have characteristics to be less desired. However, design engineer who is the decision maker is the one who finalize the selection process. Decision variables d_3^-, d_4^-, d_7^- represent that the criterion for the selected equipment is less than the desired goal with a minimum deviation which is the expected.

4. CONCLUSION

In the first stage of this study, the criteria for selecting the ship wastewater treatment system with the design perspective are determined, the criteria are prioritized by AHP method and the optimum solution among the alternatives is chosen by AHP method. In the second stage, technical constraints are determined within the scope of equipment integration and 0-1 Goal Programming method is used in a hybrid manner with AHP in order to find the optimum solution for these constraints. The AHP weights of the alternatives are plugged in as a constraint to the model.

Among the criteria according to AHP method's solution, Capacity has the largest share and dominates other criteria. The capacity of the wastewater treatment system is the most important input for the design. The selection of equipment below the minimum capacity to be produced by the personnel, inevitably issues problems in the long term. The second most important criterion is the volume requirement. It is very critical that the equipment to be selected can be located in the designated location in the ship. The weights of other criteria are shown in Table 4. With the use of criteria weights as model inputs, a selection is made between 5 alternative equipment items by using AHP method and the results of the selection are shown in Table 5. Accordingly, equipment “E” is chosen as the optimal solution.

0-1 Goal Programming method is applied by using technical constraints as model input. Accordingly, equipment “E” is also determined as the optimum solution. Table 7 shows the deviations from the model constraints of selected alternative according to AHP and 0-1 Goal Programming solutions.

The equipment “E” is selected by 0-1 Goal Programming and AHP with minimum deviation of “1.7”. The height value with a negative deviation of 29 mm and weight value with a negative deviation of 633 kg is lower than the specified limit. Length, Width and Power Requirement characteristics of equipment “E” is more than the desired value. Besides, Capacity value of the equipment “E” is the highest among others. From a combined AHP and GP point of view, once AHP is considered as a constraint and forced to satisfy both negative and positive deviations, AHP weights of alternatives dominate other criteria. As mentioned above in this problem, equipment "E" is selected since it has the highest priority level according to AHP. The decision maker, namely the design engineer has to consider that such deviations are to be within tolerable limits where a tolerable limit can be defined as the deviation that does not yield to an over-design.

Table 7. Comparison of AHP and 0-1 Goal Programming Results

Resources	Targeted Goals	AHP and 0-1 Goal Programming Deviation (Equipment E
Length	3000 mm	72
Width	1900 mm	380
Height	2000 mm	29 (slack)
Weight	8000 kg	633
Power Req.	6 kW	0.2
Capacity	6.75 m^3/day	2.61

5. FUTURE STUDY

In this study, combined AHP and 0-1 Goal Programming methods are used to select Marine Wastewater Treatment Plant. It is observed that AHP weights of alternatives dominate other goals in Goal Programming. To elaborate the effect of such hybrid methods, it is highly recommended that researchers carry out GP analysis without AHP goal. Another study can be carried out that AHP weights of selection criteria can be plugged into objective function so that each criteria is evaluated with respect to its priority.

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APPENDIX

Table 8. Pair-wise Comparison Matrix of Criteria (Geometric Mean)

	Ease of Operation	Ease of Integration	Volume Req.	Weight	Capacity	Power Req.
Ease of Operation	1.00	3.64	0.33	0.41	0.14	0.58
Ease of Integration	0.27	1.00	0.22	0.41	0.12	0.94
Volume	3.06	4.58	1.00	6.85	0.24	2.59
Weight	2.43	2.43	0.15	1.00	0.11	0.61
Capacity	7.30	8.45	4.21	9.00	1.00	7.94
Power Req.	1.73	1.06	0.39	1.63	0.13	1.00

Table 9. Pair-wise Comparison Matrix of Alternatives in terms of "Ease of Operation" (Geometric Mean)

	A	B	C	D	E
A	1.00	0.33	0.61	2.28	0.58
B	3.00	1.00	3.48	1.32	2.24
C	1.63	0.29	1.00	1.32	0.35
D	0.44	0.76	0.76	1.00	0.76
E	1.73	0.45	2.82	1.32	1.00

Table 10. Pair-wise Comparison Matrix of Alternatives in terms of "Ease of Integration" (Geometric Mean)

	A	B	C	D	E
A	1.00	0.58	0.92	1.73	0.76
B	1.73	1.00	2.59	1.32	1.50
C	1.09	0.39	1.00	1.00	0.47
D	0.58	0.76	1.00	1.00	0.76
E	1.32	0.67	2.14	1.32	1.00

Table 11. Pair-wise Comparison Matrix of Alternatives in terms of "Volume Requirement" (Geometric Mean)

	A	B	C	D	E
A	1.00	0.18	0.19	7.94	3.41
B	5.54	1.00	0.76	9.00	5.92
C	5.21	1.32	1.00	9.00	5.92
D	0.13	0.11	0.11	1.00	0.38
E	0.29	0.17	0.17	2.65	1.00

Table 12. Pair-wise Comparison Matrix of Alternatives in terms of "Weight" (Geometric Mean)

	A	B	C	D	E
A	1.00	0.58	1.00	8.45	0.44
B	1.73	1.00	2.28	8.45	1.00
C	1.00	0.44	1.00	7.94	0.58
D	0.12	0.12	0.13	0.25	0.11
E	2.28	1.00	1.73	9.00	1.00

Table 13. Pair-wise Comparison Matrix of Alternatives in terms of "Capacity" (Geometric Mean)

	A	B	C	D	E
A	1.00	1.00	1.73	0.49	0.38
B	1.00	1.00	1.73	0.45	0.35
C	0.58	0.58	1.00	0.45	0.33
D	2.06	2.24	2.24	1.00	0.45
E	2.65	2.82	3.00	2.24	1.00

Table 14. Pair-wise Comparison Matrix of Alternatives in terms of "Power Requirement" (Geometric Mean)

	A	B	C	D	E
A	1.00	0.29	0.16	0.11	0.18
B	3.41	1.00	0.23	0.13	0.51
C	6.44	4.40	1.00	0.20	3.87
D	9.00	7.45	4.88	1.00	5.54
E	5.44	1.97	0.26	0.18	1.00