



Selection of Material for Marine Environments Using Fuzzy TOPSIS Approach

Araştırma Makalesi/Research Article

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Abstract— Material selection for marine environments is an important, difficult, and complex process. For the purpose of decision support, a model was created for the selection of materials for marine environments with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method, which is used for decision-making in fuzzy environments. The decision criteria in the model were determined by an expert, and according to these decision criteria, alternative materials were evaluated with linguistic variables. In the model, there were four main criteria (corrosion resistance, cost, mechanical properties, and workability) and four sub-criteria (yield strength, tensile strength, hardness, and elongation) under the main criteria of mechanical properties. Alternative materials were ranked according to the criteria and alternative material evaluations which were determined by the expert. The software that the created model was applied, developed in the programming language Visual C#. Thanks to the software, decision-makers can obtain different rankings easily by changing the criteria weights and select material for different environments. In the result of the study, applying sensitivity analysis, impact and priority ranking criteria were evaluated.

Keywords—TOPSIS, material selection, fuzzy logic, multi- criteria decision making

Bulanık TOPSIS Yaklaşımı ile Denizel Ortamlar için Malzeme Seçimi

Özet— Denizel ortamlar için malzeme seçimi önemli, zor ve karmaşık bir süreçtir. Karar destek amacıyla, bulanık ortamlarda karar vermek için kullanılan Bulanık İdeal Çözüm Benzerliği Tercih Sıralaması Tekniği (TOPSIS) yöntemi ile denizel ortamlar için malzeme seçilmesine yönelik bir model oluşturulmuştur. Modelde yer alan karar kriterleri bir uzman tarafından belirlenmiş ve bu karar kriterlerine göre alternatif malzemeler dilsel değişkenler ile değerlendirilmiştir. Modelde, dört ana kriter (korozyon direnci, maliyet, mekanik özellik ve işlenebilirlik) ve mekanik özellik ana kriteri altında dört alt kriter (akma mukavemeti, çekme mukavemeti, sertlik ve uzama) bulunmaktadır. Uzman tarafından belirlenen kriter ve alternatif değerlendirmelerine göre alternatif malzemeler sıralanmaktadır. Visual C# programlama dilinde oluşturulan modelin uygulandığı bir yazılım geliştirilmiştir. Yazılım sayesinde karar vericiler kriter ağırlıklarını değiştirerek kolayca farklı sıralamalar elde edebilir ve farklı ortamlar için malzeme seçebilirler. Çalışma sonucunda, oluşturulan modele duyarlılık analizi uygulanarak, kriterlerin etkisi ve öncelik sıralamaları yeniden değerlendirilmiştir.

Anahtar Kelimeler—TOPSIS, malzeme seçimi, bulanık mantık, çok kriterli karar verme

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1. INTRODUCTION

An ever-increasing competition environment, the importance that enterprises attach to decision-making applications also increases. Both when daily decisions and work-related decisions are in question; the increase of parameters that are capable of affecting our decisions, the case of alternatives in evaluation having unique characteristics, causes the selection to be made to become complicated. The fact that the error rate being high among the heuristical made decisions, led people to look for scientific methods in science and technology for the solution of decision-making problems. For the purpose of evaluating and analyzing of the criteria which were effective for the decision to be made, multi-criteria decision-making (MCDM) models have been developed [1]. There are several multi-criteria decision making methods that can be used in the decision process. The decision maker should choose the most appropriate method for the decision, considering the nature and extent of the problem, and process characteristics [2, 3].

The selection of most proper materials in engineering design is known as an important stage of the design process [4]. The material selection problem is a multi-criteria decision-making process, it generates troublous consequences for many companies. When the fields of usage are considered in a widely; it is certain for a wrong decision to result in vital consequences. Thus, a certain amount of attention and sensitivity should be involved in selections. For this purpose, using a scientific method in the decision-making process will be more efficient than just a heuristical and empirical decision-making process.

It has been investigated by many researchers for more than 20 years that to find the most proper material in various applications [4]. There are many studies available in literary in which fuzzy logic approach was used for material selection and decision-making processes in various fields [5–7]. One of these studies, presented by Chen (1997), aims to select the ideal material by using trapezoidal numbers from fuzzy approach methods in a system consisting of many criteria and alternative materials [8]. One similar study by Mayyas et al. [9] presented a sustainability model for eco-material selection as applied to the automobiles' body panels using the fuzzy TOPSIS method. All candidate materials for 20 attributes were evaluated using triangular fuzzy numbers. They ranked of the first six materials using several multi-attribute decision-making methods used in the eco-material selection for auto-bodies. And Thakker et al. (2008), have put forward, including TOPSIS, one of the multi-criteria decision making methods [10]. What is aimed at the end of a multi-criteria decision process is carrying out the process of choosing the ideal material to be used in producing turbine blades. Meanwhile, Eleren and Ersoy (2007) aim to determine the ideal cutting method for the marble blocks, using TOPSIS which is one of the multi-criteria decision-making methods [11]. Also, Jee and Kang (2000) has made the selection of the most ideal material using the TOPSIS method [12]. In their study, particularly the

possibility of materials varying performance for different conditions is being focused on and entropy at this point is being remarked. Considering this entropy, the usage of a computer-aided expert system software is foreseen. In another study in which the PVC pipes selection was made using multi-objective decision-making a computer-aided expert system software was used [13]. Six candidate materials were evaluated according to properties like on-toxic, corrosion resistant, cheap, UV radiations resistant and tough. For evaluation, the performance equation and material index were defined and then the candidate materials were ranked using the digital logic method.

Okokpujie et al. (2020) used AHP and TOPSIS, two multi-criteria decision methods in selecting a suitable material for developing a horizontal wind turbine blade [14]. Four alternatives were evaluated by using the data obtained from the 130 research questionnaire. Expressed that the AHP and TOPSIS methods used were workable for material selection practice in the result of the study. In another study, used algorithms of TOPSIS and VIKOR to determine the most suitable carbon steel alloy for the design of freight wagon bogie [5]. Similar results were obtained in both methods for the model that was evaluated for 4 alternative materials and it shows the significance of the created problem matrix. As in many engineering fields, in the field of bioengineering, the selection of materials has become an increasingly important issue. In a study in this field, a computer-aided model was created to select the optimal material for total hip implant [4]. For this purpose, computerized tomography data were used and optimal material alternatives were investigated. The best material candidate was selected with the help of software in the model created for the defined criteria and material properties. It was stated that the results of the study had a positive effect upon the total hip arthroplasty operations.

In the material selection process, one of the most important evaluation criteria is the environment in which the material is used. Evaluation criteria and alternative materials are determined considering the environmental conditions. In a study evaluating the marine environments, Yadav et al. proposed a novel hybrid TOPSIS-PSI methodology which helps in choosing the best alternative material in marine conditions which was carried out for hybrid aluminium nano composites [15]. The advantages of both the techniques (TOPSIS and PSI) were considered and a logical procedure was developed. It is expressed that the TOPSIS method is more proficient in dealing with the physical attributes and the number of available alternatives. Selecting Multi-Purpose Tugboat / AHT (Anchor Handling Tug) to be used in marine environments was selected by using MOORA and TOPSIS methods, the geographic challenges of the region (especially low water depth) taken into consideration for selection [16]. Methods in which alternatives were evaluated, were tested by Kendall's Coefficient of Concordance. It was stated that, results of used methods conform with each other and provide convenience to the maritime companies in the North Caspian Sea for selection.

Also Cicek and Celik (2009), proposed a decision aid mechanism based on Fuzzy Axiomatic Design (FAD) to select adequate form of porous materials in marine systems design [17]. The proposed model and material selection procedure were applied successfully to a case study, were intended to be useful for professional marine engineers and naval engineers.

The aim of this study is to select the ideal material by using fuzzy logic approach in multi-criteria decision making processes for marine environments. For discussing uncertainty in the decision-making process, proposed a solution to the problem with the fuzzy TOPSIS method and the software was developed.

2. MATERIAL AND METHOD

The materials to be selected at the end of the application will be used in marine environments. Many conflicting multiple amounts of criteria are taken into account in the material selection problem since some of the qualitative criteria required for the selection cannot be expressed with accurate amounts; these variables are ignored and not included in the analyses, in classical multi-criteria method in which accurate numbers are used. These methods do not have the ability to deal with the fuzziness and uncertainty that decision-makers come across during the deciding process [18]. In this regard, Fuzzy TOPSIS method, one of the fuzzy multi-criteria decision-making methods, is recommended to approach the selection of the most ideal material to be used in marine environments problem.

2.1. Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method

For the evaluation of materials to be used in marine environments, the study used the TOPSIS technique. Firstly, the fuzzy numbers and linguistic terms used in the method will be mentioned.

Fuzzy Numbers and Linguistic Terms

Fuzzy set theory was developed for making decisions for problems dealing with impreciseness, uncertainty, and subjectivity by Lofti Zadeh (1965) [19]. A fuzzy number is a quantity whose value is imprecise, rather than exact as is the case with “ordinary” (single-valued) numbers. Any fuzzy number can be thought of as a function whose domain is a specified set usually the set of real numbers, and whose range is the span of non-negative real numbers between, and including, 0 and 1. Each numerical value in the domain is assigned a specific “grade of membership” where 0 represents the smallest possible grade, and 1 is the largest possible grade [20].

There are different shapes of fuzzy membership functions (MF) such as triangle, trapezoidal, gaussian, and sigmoidal. The triangular and trapezoidal MFs are formed by using straight lines which provides the advantage of simplicity [21].

As mentioned above fuzzy membership functions have different forms; however, the linear forms (i.e., triangular shapes) are suitable for most practical applications [22]. Therefore, triangular fuzzy numbers are used in this article.

Triangular fuzzy numbers as in Figure 1; being a specific type of fuzzy numbers defined with three floating point number are expressed as (l, m, u) .

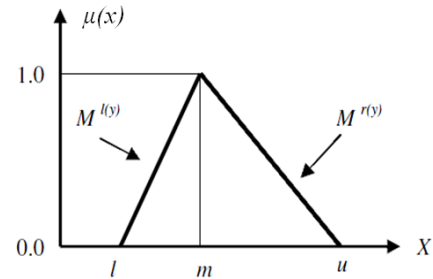


Figure 1. Fuzzy triangular number (l, m, u)

Parameters (l, m, u) express minimum possible number value, the most probable value and maximum possible value in order. The values' membership (weight) is 0, while all the numbers between l and u have a weight in the interval $[0-1]$ (membership function) [7].

When processing with a triangular number, linear presentation of the number with regard to its right and left values are as such:

$$\mu(x | \tilde{M}) = \begin{cases} 0, & x < l, \\ (x-l)/(m-l), & l \leq x \leq m, \\ (u-x)/(u-m), & m \leq x \leq u, \\ 0, & x \geq u. \end{cases} \quad (1)$$

TOPSIS Method

The arrangement method of factoring the distance to the ideal solution (TOPSIS) which is one of the multi-criteria decision-making methods is a method first developed by Hwang and Yoon [23].

It is one of the most preferred methods for resolving the multi-criteria decision problem due to it uses the subjective preferences for criteria evaluation and evaluates impreciseness variables with fuzzy numbers [19, 24].

When providing a solution with this method, the distance of all positive and negative alternatives to the ideal solution is calculated. The case of a selected alternative being in the shortest distance to the positive ideal solution and in the longest distance to the negative ideal solution at the same time forms the basis of TOPSIS approach. TOPSIS method acknowledges the alternative in the shortest distance to the positive ideal solution as the best alternative [23].

In Figure 2, the algorithm of Fuzzy TOPSIS Method is given.

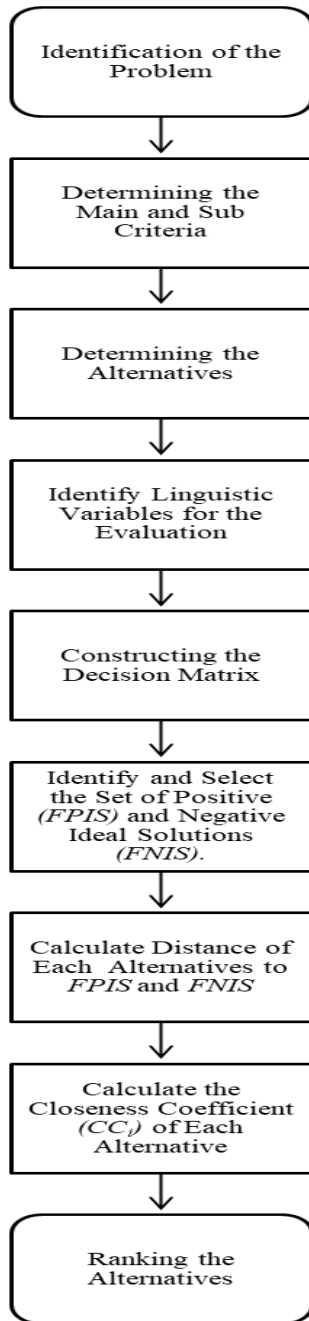


Figure 2. Fuzzy TOPSIS algorithm

Steps of the method are briefly explained:

Step 1: Decision maker group and evaluating criteria are determined.

Step 2: Linguistic variables in Table 1 for criteria to be weighted and linguistic scores in Table 2 for alternatives to be evaluated are generated.

Table 1. Linguistic variables for criteria

Linguistic Variables	Fuzzy Numbers
Very Low (VL)	(0.0, 0.0, 0.1)
Low (L)	(0.0, 0.1, 0.3)
Medium Low (ML)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium High (MH)	(0.5, 0.7, 0.9)
High (H)	(0.7, 0.9, 1.0)
Very High (VH)	(0.9, 1.0, 1.0)

Table 2. Linguistic variables for alternatives

Linguistic Variables	Fuzzy Numbers
Very Poor (VP)	(0, 0, 1)
Poor (P)	(0, 1, 3)
Medium Poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium Good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very Good (VG)	(9, 10, 10)

Step 3: Evaluations that N amounts of decision makers carry out for criteria and alternatives are combined. Here, \tilde{x}_{ij}^N indicates the evaluation of N decision-maker and \tilde{w}_j^N indicates the significance of N decision-maker.

$$\tilde{x}_{ij} = \frac{1}{N} [\tilde{x}_{ij}^1 \otimes \tilde{x}_{ij}^2 \otimes \dots \otimes \tilde{x}_{ij}^N] \quad (2)$$

$$\tilde{w}_j = \frac{1}{N} [\tilde{w}_j^1 \otimes \tilde{w}_j^2 \otimes \dots \otimes \tilde{w}_j^N] \quad (3)$$

Step 4: The Decision Problem is presented in matrix format in Equation 4 after a single value for all the criteria and alternatives is generated.

Here, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$ being triangular fuzzy numbers, \tilde{D} indicates fuzzy decision matrix, and \tilde{W} indicates fuzzy weights matrix.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad \tilde{W} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n] \quad (4)$$

Step 5: The step after the generation of decision matrix is the normalization of decision matrix. The fuzzy decision matrix is normalized with the help of equation 6 and 7 and normalized fuzzy decision matrix \tilde{R} is obtained.

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (5)$$

B and C are profit and cost criteria;

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), \quad j \in B, \quad c_j^* = \max_i c_{ij}, \quad (6)$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right), \quad j \in C, \quad a_j^- = \min_i a_{ij}, \quad (7)$$

Here, $\tilde{r}_{ij}, (\forall i, j)$ resemble normalized triangular fuzzy numbers.

Step 6: Taking the fact that each decision criteria might have different significance into factor after the normalized fuzzy deciding matrix is generated, the weighted normalized fuzzy decision matrix is generated in this manner:

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (8)$$

Here it is expressed as, $\tilde{v}_{ij} = \tilde{r}_{ij}(\cdot)\tilde{w}_{ij}$

Step 7: After normalized fuzzy decision matrix is generated, fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FNIS, A^-) are identified as:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \quad A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) \quad (9)$$

Here it is expressed as, $\tilde{v}_j^* = (1, 1, 1)$ and $\tilde{v}_j^- = (0, 0, 0) \quad j = 1, 2, \dots, n$

Step 8: And then, distance of each alternative to the positive ideal solution (A^*) and negative ideal solution (A^-) is calculated. Here, $d(\cdot, \cdot)$ indicates the distance between two fuzzy numbers and is calculated with the help of vertex method.

$$d_i^* = \sum_{j=1}^n d_v(\tilde{v}_{ij}, \tilde{v}_j^*) \quad i = 1, 2, \dots, m$$

$$d_i^- = \sum_{j=1}^n d_v(\tilde{v}_{ij}, \tilde{v}_j^-) \quad i = 1, 2, \dots, m \quad (10)$$

Step 9: Closeness Coefficient of each alternative are calculated and ranked the order of alternatives.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad , \quad i = 1, 2, \dots, m \quad (11)$$

2.2. Optimal Material Selection

The environment in which the material will be used is the most important parameter in material selection. Alternative materials and criteria to be used in the evaluation should be determined according to the environmental properties. For this purpose, in the decision-making process of the problem, criteria were determined by making use of the expert opinion and literature [4, 7, 14, 17].

Eight alternative materials were determined by the expert according to the laboratory measurement results of the candidate materials for considering criteria, as shown in Table 3.

Since the material selected in this study will be used in marine environments, the evaluation criteria were determined in accordance with the environment. The most significant characteristics of marine environments are the bigger amount of salt involved than in the aqueous mediums. Although it varies in different areas, the amount of salt is a factor that affects material selection to a considerable extent. The long lifespan of the material,

being resistant to corrosive conditions, being in the desired cost range and its mechanical properties meeting the requirements draws it closer to the ideal.

Table 3. Alternative materials

1. Alternative Material (A1)	316 L (Stainless Steel)
2. Alternative Material (A2)	Brass (70% Copper - 30% Zinc-Heat Treatment)
3. Alternative Material (A3)	Titanium (Ti6Al4V - Heat Treatment)
4. Alternative Material (A4)	Cast Iron (32510 Ferritik)
5. Alternative Material (A5)	Aluminium (6009 - T6 Heat Treatment)
6. Alternative Material (A6)	Magnesium (AZ91E - T6 Heat Treatment)
7. Alternative Material (A7)	Nickel Alloy (NI 625 Super Alloy - Heat Treatment)
8. Alternative Material (A8)	Low- Carbon Steel (1030 - Heat Treatment - Quenched)

In the model, there were four main criteria (corrosion resistance, cost, mechanical properties, and workability) and four sub-criteria (yield strength, tensile strength, hardness, and elongation) under the main criteria of mechanical properties, and the evaluation was made accordingly these criteria. The selected criteria were defined as follows are shown in Figure 3.

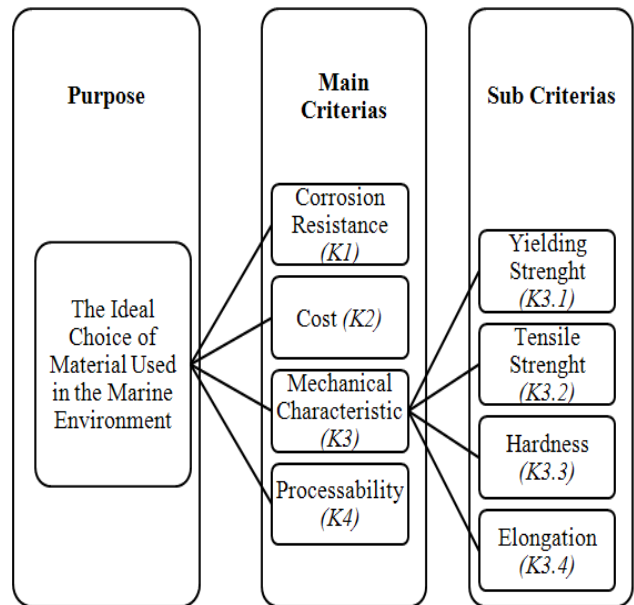


Figure 3. Main and sub criteria used for material selection

a. Corrosion Resistance (K1): For each material, no matter the conditions, the demand is the material’s ability to preserve its characteristics since the day one. Material’s ability to preserve itself without changing phases in the ambience it is in, is a very important factor in engineering [25]. On the contrary, corrosion is the event of metals disintegration reacting with its ambience and a basic law of nature [26]. Although it is possible to drastically slow down the corrosion and extend the lifespan of the material, it is not a completely preventable event [25]. Material distortion happening due to the electrochemical effect of the environment results in significant amounts of

economical loss, particularly causing crucial problems on metals [27]. For this reason, corrosion should not only be seen as a chemical characteristic of the material but the cost factor should also be taken into account. Corrosion resistance criteria is one of the most important parameters in which evaluated the materials to be used in marine environments [28, 29]. Due to the fact that corrosion not being completely preventable, when other conditions are ignored, selection of the one with the higher corrosion resistance provides a better performance.

b. Cost (K_2): In today's competition environment for selection to be acknowledged as ideal, costs should also be in the demanded range. Due to the fact that reserved budget that is in direct proportion with costs will lead to changes in material selection, it has a major effect on the evaluation. The importance that the enterprise places on cost criteria and the budget it reserves when selecting the material it will use might alter the outcome.

c. Mechanical Properties (K_3): Is defined as the mechanical reaction behavior of a material's resistance against the forces applied. This behavior is detected by measuring and observing the strain and form changes under different kinds of pressures. Together with interatomic bond forces being the source of mechanical properties, it is impossible to establish a direct bond between them because of the fact that they are heavily bound to the internal structure and environment conditions. Therefore the theories on atoms are efficient in clarifying many events qualitatively but insufficient in terms of quantity. Thus, it is necessary to take the changes in the internal structure into consideration [27]. A wider knowledge of the material can be accessed by taking advantage of these changes. For instance, characteristics such as resistance, hardness and toughness do not only affect the materials lifecycle but also affects the selection of the production processes to be applied to that specific material [30].

In this study, yielding and tensile strengths of the materials, their hardness and their percentage elongation rates are used as the criteria. Alternative materials are evaluated for the sub-criteria depending their sufficiency to this ambiance and the selection of the ideal material is maintained.

c.1. Yielding Strength ($K_{3,1}$): It can also be defined as the stretching creating 0.2% plastic transformation or as the transition from the elastic transformation to plastic transformation. To find out the yielding strength taking advantage of this definition, 0.2% spot on the transformation axis of the diagram obtained with perpetual renewal is marked and a parallel to diagrams direct part is drawn. The strain that match up to the point where this parallel intercepts the curved line, is the value of yielding strength [27].

c.2. Tensile Strength ($K_{3,2}$): It is a properties that indicates traction load (strain) of the material without breaking [30]. If the tensile strength is to be expressed with the relation between the mechanical properties; due to the fact that the

strain and stretching will reach the maximum if the material is kept being applied force after the tensile point, strength attained at this point gives the cross-section the resistance to lift the ratio.

c.3. Hardness ($K_{3,3}$): It is the resistance of a material to a hard object that is pressed on its surface. In a sense, hardness can be supposed as the resistance of the material to plastic transformation, accordingly it is not related to tensile strength [27]. Hardness rates of the material, cannot be numerically used for designing processes as yielding strength and tensile strength and determine the qualitative aspect of the material. When this aspect is being determined, a standard load is applied on the sample material with a hard plunger-type object. The hardness of the material is measured according to impact (area and depth) of the force applying object [30].

c.4. Elongation($K_{3,4}$): It is closely related to stretching which is another mechanical properties. Multiplication of division of total elongation until the breaking point to the length at the beginning with 100 is elongation ratio. Ratio decrease of cross-sectional area or elongation ratio is a measurement of material durability [31].

d. Workability (K_4): It is not a universally identified; quantitative; standard characteristic. Generally, the materials ability to be processed; in other words, the materials level of difficulty to be shaped with a cutting tool is called workability. Characteristics of the metallurgy of the material used, such as its chemical structure, mechanical properties, thermal processing, admixtures, remnants, the thickness of the hard layer on the surface etc. have effects on factors such as cutting edge, toolkit connecting pattern, toolkit bench, the basis of processing, and processing conditions [5, 14].

3. MODEL APPLICATION

3.1. Application

In this study, 8 candidate material alternatives (A1-...-A8) were evaluated with the fuzzy TOPSIS method using application software developed by the author. Defining the material selection problem and the steps involved in the computation were summarized below.

Step 1: Alternatives and criteria determined by the expert.

Step 2: The evaluations of the criteria and sub-criteria made by the expert using the linguistic variables in Table 1 are shown in Figure 4.

Accordingly, it has seen that the expert preferred the material to be used in the marine environment to have "Very High" of Corrosion Resistance and "Medium Low" of Cost, "High" of Mechanical Properties, "Very High" of Yielding Strength, "High" of Tensile Strength, "Medium Low" of Hardness, "Medium" of Elongation and "Medium" of Workability.

Figure 4. Evaluation criteria

Alternative materials were evaluated by the expert according to the main and sub-criteria (K₁-...-K₄) for the materials to be used in marine environments using the linguistic variables in Table 2.

The evaluations for the alternatives are shown in Figure 5. Similarly, the expert evaluated alternative materials for the criteria of Corrosion Resistance making use of its experience. According to expert opinion and evaluation, Corrosion Resistance of 316L is “Good”, while Brass is “Fair”, Titanium is “Very Good”, Cast Iron is “Fair”, Aluminium is “Medium Poor”, Magnesium is “Very Poor”, Nickel Alloy is “Good” and Low-Carbon Steel is “Poor” in marine environments.

Figure 5. Evaluation alternatives

Step 3: In spite of the TOPSIS method provides that the evaluation for more than one decision-maker with different

importance weights, in this study, the evaluation was made by one decision-maker.

Step 4: In the Table 4, the fuzzy decision matrix which includes the criteria’s weights were given. The criteria weights in Table 4. Fuzzy Decision Matrix were determined using Eq.(4) according to the decision maker's evaluation in Figure 4.

For example, as in Figure 4, the decision-maker evaluation results of K1. Corrosion Resistance criteria is "Very High". Using Table 1 Linguistic variables for criteria, the fuzzy numbers corresponding to this linguistic variable is determined as (0.90, 1.00, 1.00). For the K2. Cost criteria, it is determined as (0.10, 0.30, 0.50) according to the linguistic variable "Medium Low" evaluation of the decision-maker.

The values of the alternatives are determined according to the Figure 5. Accordingly, 316L (A1) alternative material evaluated as “Good” for the K1. Corrosion Resistance criteria is determined as (7, 9, 10) using Table 2. Linguistic variables for alternatives. According to the evaluation of the "Fair" linguistic variable for Brass (A2) material, the fuzzy numbers determined as (3, 5, 7).

Step 5: Identifying the Weighted Normalized Fuzzy Decision Matrix table, the fuzzy numbers of the alternatives in Table 4 were first normalized with the help of Eqs. (6,7). Normalization process used in this study; obtained by dividing all the values in the row by the maximum value of that row. In this way, the normalized fuzzy decision matrix was determined.

For example, The normalized value (0.7, 0.9, 1) was obtained by dividing the A1 row for the K1 criteria (7, 9, 10) with the rows maximum value by 10.

Step 6: Values derived from the multiplication of normalized fuzzy decision matrix with the related criteria’s weights were represented in Table 5 using Eq. (8). In this process, the criteria weights values and normalized fuzzy decision matrix values were multiplied.

For the K1 criteria of the A1 alternative; Weighted Normalized Fuzzy Decision Matrix value (0.63,0.90, 1.00) was obtained by multiplying the criteria weight (0.90,1.00,1.00) with the normalized fuzzy value of the alternative (0.7, 0.9, 1).

Step 7: In this study, fuzzy positive ideal solution and fuzzy negative ideal solution were determined as follows.

$$A^* = (1, 1, 1)$$

$$A^- = (0, 0, 0)$$

Table 4. Fuzzy decision matrix

weights	K ₁	K ₂	K _{3,1}	K _{3,2}	K _{3,3}	K _{3,4}	K ₄
	(0.90,1.00,1.00)	(0.10,0.30,0.50)	(0.63,0.90,1.00)	(0.49,0.81,1.00)	(0.07,0.27,0.50)	(0.21,0.45,0.70)	(0.30,0.50,0.70)
A1	(7, 9, 10)	(0, 1, 3)	(1, 3, 5)	(1, 3, 5)	(7, 9, 10)	(5, 7, 9)	(9, 10, 10)
A2	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)	(0, 0, 1)	(9, 10, 10)	(9, 10, 10)
A3	(9, 10, 10)	(0, 0, 1)	(9, 10, 10)	(9, 10, 10)	(9, 10, 10)	(1, 3, 5)	(1, 3, 5)
A4	(3, 5, 7)	(9, 10, 10)	(0, 1, 3)	(0, 1, 3)	(5, 7, 9)	(0, 1, 3)	(5, 7, 9)
A5	(1, 3, 5)	(5, 7, 9)	(0, 1, 3)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(9, 10, 10)
A6	(0, 0, 1)	(3, 5, 7)	(0, 0, 1)	(0, 0, 1)	(3, 5, 7)	(0, 0, 1)	(3, 5, 7)
A7	(7, 9, 10)	(0, 1, 3)	(7, 9, 10)	(3, 5, 7)	(7, 9, 10)	(7, 9, 10)	(1, 3, 5)
A8	(0, 1, 3)	(7, 9, 10)	(3, 5, 7)	(7, 9, 10)	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)

Table 5. Weighted normalized fuzzy decision matrix

	K ₁	K ₂	K _{3,1}	K _{3,2}	K _{3,3}	K _{3,4}	K ₄
A1	(0.63,0.90, 1.00)	(0.00,0.03,0.15)	(0.06,0.27,0.50)	(0.05,0.24,0.50)	(0.05,0.24, 0.50)	(0.11,0.32,0.6)	(0.27,0.50,0.70)
A2	(0.27,0.50,0.70)	(0.03,0.15,0.35)	(0.32,0.63,0.90)	(0.15,0.41,0.70)	(0.00,0.00,0.05)	(0.19,0.45,0.70)	(0.27,0.50,0.70)
A3	(0.81,1.00,1.00)	(0.00,0.00,0.05)	(0.57,0.90,1.00)	(0.44,0.81,1.00)	(0.06,0.27,0.50)	(0.02,0.14,0.35)	(0.03,0.15,0.35)
A4	(0.27,0.50,0.70)	(0.09,0.30,0.50)	(0.00,0.09,0.30)	(0.00,0.08,0.30)	(0.04,0.19,0.45)	(0.00,0.05,0.21)	(0.15,0.35,0.63)
A5	(0.09,0.30,0.50)	(0.05,0.21,0.45)	(0.00,0.09,0.30)	(0.05,0.24,0.50)	(0.02,0.14,0.35)	(0.02,0.14,0.35)	(0.27,0.50,0.70)
A6	(0.00,0.00,0.14)	(0.04,0.21,0.50)	(0.00,0.00,0.14)	(0.00,0.00,0.14)	(0.03,0.19,0.50)	(0.00,0.00,0.10)	(0.13,0.36,0.70)
A7	(0.63,0.90,1.00)	(0.00,0.03,0.15)	(0.44,0.81,1.00)	(0.15,0.41,0.70)	(0.05,0.24,0.50)	(0.15,0.41,0.70)	(0.03,0.15,0.35)
A8	(0.00,0.10,0.30)	(0.07,0.27,0.50)	(0.19,0.45,0.70)	(0.34,0.73,1.00)	(0.04,0.19,0.45)	(0.06,0.23,0.49)	(0.15,0.35,0.63)

Step 8: Distance of each alternative to the positive ideal solution (A*) and negative ideal solution (A⁻) was calculated with the help of vertex method. This value is determined by applying Eq. (10) as the distance of each alternative to the positive ideal solution (1,1,1) and negative ideal solution (0,0,0) was calculated. Since triangular fuzzy numbers were used in this study, the distances were calculated using Eq (12).

$$d(m, n) = \sqrt{\frac{1}{3}((m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2)} \quad (12)$$

$$m = (m_1, m_2, m_3) \quad n = (n_1, n_2, n_3)$$

Accordingly, the distances of the A1 alternative material from positive and negative ideal solutions for the Corrosion Resistance (K1) criteria were calculated as follows:

$$d(A1, A^*) = \sqrt{\frac{1}{3}((1 - 0.63)^2 + (1 - 0.9)^2 + (1 - 1)^2)} = 0.2212841$$

$$d(A1, A^-) = \sqrt{\frac{1}{3}((0 - 0.63)^2 + (0 - 0.9)^2 + (0 - 1)^2)} = 0.8576906$$

The d_i^{*} and d_i⁻ values were determined by summing the calculated distance values for all criteria, as shown in Table 6.

Step 9: Closeness Coefficients are the ultimate indicators of the distance of alternative analyzed from the ideal solutions and these parameters vary from 0 to 1. Closeness

Coefficient of each alternative are calculated using distances for all alternatives using Eq. 11.

$$CC_1 = \frac{d_i^-}{d_i^* + d_i^-} = \frac{2.852207}{4.649511 + 2.852207} = 0.380207$$

Closeness Coefficient of each alternative were calculated and ranked the order of alternatives as shown in Table 6. In this ranking, the alternative with the greatest closeness coefficient parameter means it is the closest alternative to the ideal.

Table 6. Closeness coefficient (CC) for ranking of alternative materials

	d [*]	d ⁻	Cci	Ranking
A1	4,649511	2,852207	0,380207	4
A2	4,566078	2,917567	0,389859	3
A3	4,111112	3,365658	0,450149	1
A4	5,390729	2,052942	0,275797	7
A5	5,365985	2,086218	0,279947	6
A6	6,035542	1,389842	0,187174	8
A7	4,346931	3,223277	0,425784	2
A8	4,827714	2,768176	0,364431	5

Titanium (A3) was found to be the best alternative among the eight alternatives, because its relative closeness is maximum with a value of 0,450149. The second best material is Nickel Alloy (A7) with value of relative closeness equal to 0,425784, as shown in Figure 6.

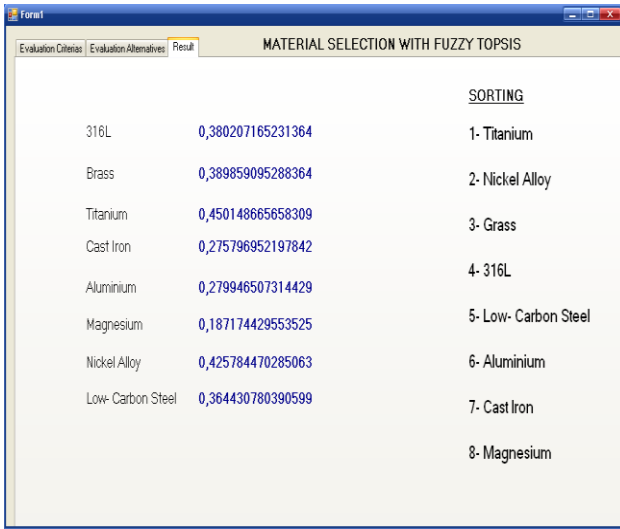


Figure 6. Results

3.2. Sensitivity Analysis of the TOPSIS Results

After the alternatives were ranked, the results of the created model should be reviewed. For this purpose, sensitivity analysis was performed to determine the robustness of the rankings of alternatives [32]. It is an important process to perform sensitivity analysis for solving multiple-criteria decision-making problems [33]. As the input data of a multiple-criteria decision-making problem are always subjective and changeable, sensitivity analysis uses for

investigate how a given model depends on its input criteria [34, 35].

A change for criteria's weights used in decision making in the material selection problem can affect the decision. For this purpose, sensitivity analysis was conducted for proposed TOPSIS model to observe the effect of weight of main criteria on the closeness index. To do this, the different criteria weights for 28 cases shown in Table 7 were utilized. Sensitivity analysis results made according to each main criteria weight were shown in Figure 7.a-d. Also, new 'Closeness Coefficient' values of alternative materials were shown according to the changing main criteria weights.

According to *Sensitivity Analysis Results of Corrosion Resistance*, A3 in the first 3 cases and A6 in other cases have the lowest closeness coefficients of TOPSIS model. A3 -Titanium's corrosion resistance is high, it leads to this result [29]. A6 in the first 5 cases and A3 in other cases have the lowest closeness coefficients of TOPSIS model, as shown in *Sensitivity Analysis Results of Cost*.

According to other analysis results, it was also seen that the A6 material has low closeness coefficient value and the ideal recommended material was changed in every case. When the sensitivity analysis results were evaluated, it was seen the ranking of material selection changes according to the weights of the criteria.

Table 7. Criteria weights for cases

	K ₁	K ₂	K ₃	K ₄
Case 1	Very Low	Medium	Medium	Medium
Case 2	Low	Medium	Medium	Medium
Case 3	Medium Low	Medium	Medium	Medium
Case 4	Medium	Medium	Medium	Medium
Case 5	Medium High	Medium	Medium	Medium
Case 6	High	Medium	Medium	Medium
Case 7	Very High	Medium	Medium	Medium
Case 8	Medium	Very Low	Medium	Medium
Case 9	Medium	Low	Medium	Medium
Case 10	Medium	Medium Low	Medium	Medium
Case 11	Medium	Medium	Medium	Medium
Case 12	Medium	Medium High	Medium	Medium
Case 13	Medium	High	Medium	Medium
Case 14	Medium	Very High	Medium	Medium

	K ₁	K ₂	K ₃	K ₄
Case 15	Medium	Medium	Very Low	Medium
Case 16	Medium	Medium	Low	Medium
Case 17	Medium	Medium	Medium Low	Medium
Case 18	Medium	Medium	Medium	Medium
Case 19	Medium	Medium	Medium High	Medium
Case 20	Medium	Medium	High	Medium
Case 21	Medium	Medium	Very High	Medium
Case 22	Medium	Medium	Medium	Very Low
Case 23	Medium	Medium	Medium	Low
Case 24	Medium	Medium	Medium	Medium Low
Case 25	Medium	Medium	Medium	Medium
Case 26	Medium	Medium	Medium	Medium High
Case 27	Medium	Medium	Medium	High
Case 28	Medium	Medium	Medium	Very High

4. RESULTS AND DISCUSSION

Decision-making problems present a great importance to many enterprises and decision-makers. At decision-making stage, the decision should be made after evaluating all the conditions that might affect the decision. In this study, TOPSIS which is one of the frequently used methods among multi-criteria decision-making methods for this purpose is used. Also, fuzzy logic theory has been utilized for the evaluation of human judgment and experiences which are not numerically expressible.

The selection of the material to be used in marine environments is provided with a fuzzy TOPSIS approach. A database has been created according to the analysis results of the laboratory for the materials to be selected with the application software. With the help of using the database, material selection can be made for different situations by increasing the material variety.

The software also provides the decision-maker with the opportunity to evaluate alternatives. If decision-makers do not want to evaluate the alternatives, the method is

executed according to the laboratory analysis results with the help of a button in the software.

In this study, in accordance with the demanded properties from the material and the evaluations of the decision-maker, Titanium was proposed as the most ideal material [4, 10, 17, 36]. The rationality of the conclusion from the study and the ease of usage of the presented method thanks to the application software, will provide an initiative and basis for similar studies in this field. In the study, it offers an application software in which material selection in marine environments is made for different situations by changing the criteria weights and new materials can be added.

Also in this study, assessed the sensitivity of the TOPSIS method regarding the parameter weights by sensitivity analysis and supported the suitability of the proposed model to material selection in marine environments. The sensitivity analysis of the fuzzy decision weights has confirmed that the proposed model gives appropriate and consistent final results.

The result shows that the proposed model used was sound for the study material selection for different environments thanks to the application software.

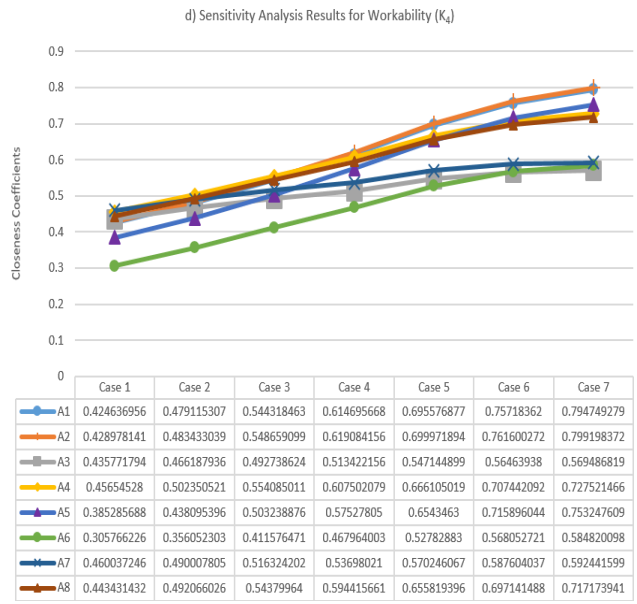
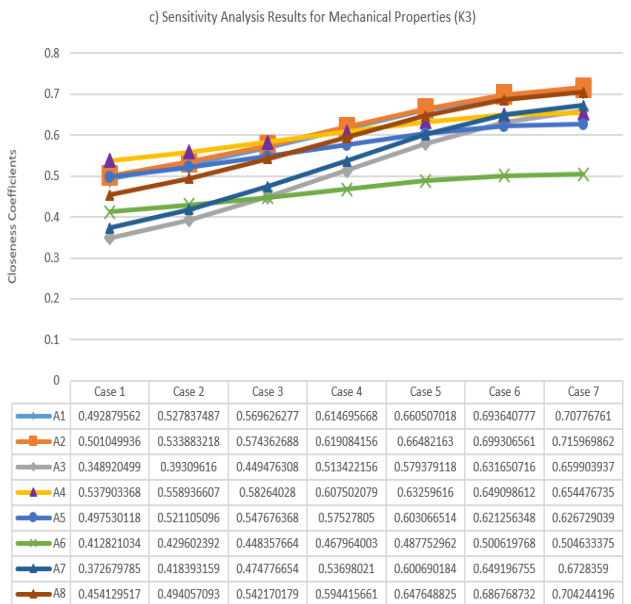
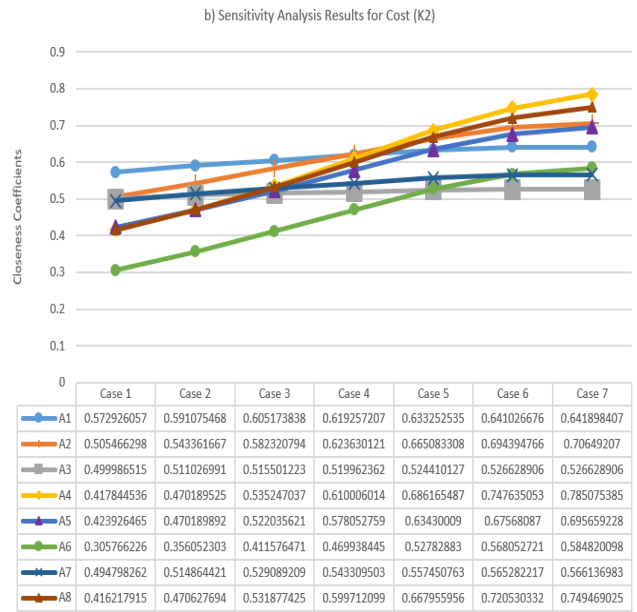
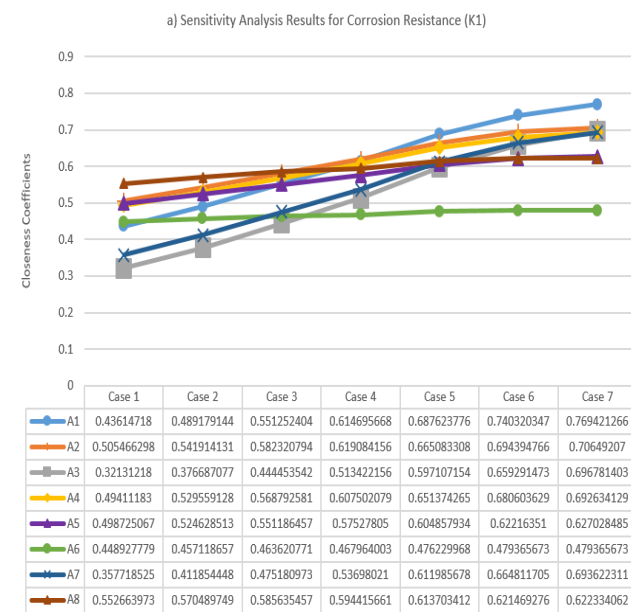


Figure 7.a-d Sensitivity analysis results of main criteria

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