IJEGEO

International Journal of Environment and Geoinformatics 10(3):024-039 (2023)

Research Article

Investigation of the Best Solution Proposals for Reducing SIRE VIQ Inspection Observations Utilizing Fuzzy TOPSIS Integrated Fuzzy DEMATEL Approach at Oil/Chemical Tankers

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Received 03.03.2023
Accepted 20.08.2023

How to cite: Yalnız and Çetin (2023). Investigation of the Best Solution Proposals for Reducing SIRE VIQ Inspection Observations Utilizing Fuzzy TOPSIS Integrated Fuzzy DEMATEL Approach at Oil/Chemical Tankers, *International Journal of Environment and Geoinformatics (IJEGEO)*, 10(3): 024-039. doi. 10.30897/ijegeo.1291867

Abstract

A significant portion of seaborne transportation is carried out by tankers. While offering huge volumes of carrying capacity, due to the characteristics of the cargoes they carry, the reliability and environment friendliness of the tanker fleets need to be maintained to ensure safe and reliable transportation without harming human life and the environment. This forms the basis of additional inspection mechanisms to keep tanker ships operationally safe. Ship Inspection Report (SIRE) programme Vessel Inspection Questionnaires (VIQ) inspections form one of the additional inspections complementing the regular Flag State and Port State Inspections. By consulting tanker crew and inspectors as field experts, this study utilizes a quantitative method to propose an approach for minimizing the most observed remarks of SIRE VIQ inspections. The study first classifies the remarks using the Fuzzy DEMATEL approach and further obtains the best possible solution suggestions via the Fuzzy TOPSIS method. The study also offers a complementary choice to add to the existing inspection routine.

Keywords: SIRE, VIQ, Safety Management, Maritime Safety Policy

Introduction

Maritime trade has always been the foundation for supporting the global supply chain. Today it is now a well-known fact that seaborne assets carry out nearly 90% of world trade. Although maritime transport continues to be highly preferred due to the high capacity it provides, it also needs to be reliable, stable, safe, and environmentally friendly. Maintaining these goals is only possible by constantly and systematically inspecting the companies engaged in maritime transport, as well as the ships and their crew engaged in actual transport. While the criteria for these inspections are sourced from the applicable national and international regulations, even though there are various methods of inspecting maritime transport elements, the tanker industry requires additional sub-inspections to get the best results. Flag State and Port State Inspections are significant means for sustaining the required standards. However, tanker transportation is perceived to deserve more scrutiny as it poses more hazardous consequences both in onboard, port, and landside operations. This is because any possible tanker accident can cause great damage to human life, the environment, and the economy due to the nature of the cargo carried. Although technological advances have contributed to the shipping industry by minimizing human interaction during operations, safety has been the reason for introducing additional inspection mechanisms regarding cargo operations, navigation, safety, and health issues for tanker ships. SIRE (Ship Inspection Report Programme) and CDI (Chemical Distribution Industry) inspections are the two main additional inspection frames for tankers. Those vetting inspections play a significant role in the final preference of oil-producing companies; hence they are vital to the ability of tanker operators to carry out their commercial activities. While Flag State and Port State inspections are mandatory, these two inspections are conducted voluntarily. However, being voluntary as they may, those inspections are as important as the mandatory ones. Because these inspections, although optional, play an essential role in ensuring the continuation of the commercial activities of tanker companies. The SIRE Program is a valuable risk assessment tool for operators and government agencies involved in tanker safety (Powers, 2008). Because large oil/chemical companies naturally prefer to work with tanker companies with a good audit trail to ensure good conduct and safety. Through those vetting inspections, freight owners aim to choose the best available companies and eliminate any possible accidents. Hence, they aim to protect human life, prevent pollution, and of course, lose their freight. In turn, tanker companies compete to secure their share of cargo in the world tanker fleet. The Oil Companies International Marine Forum (OCIMF)'s SIRE Programme aims to support tanker transport by providing a risk assessment tool and vessel inspection report database. As one of the most important inspections, SIRE Vessel Inspection Questionnaires (VIQ) for tankers are used as the primary reference of the frame and are implemented by OCIMF-accredited inspectors. (OCIMF, 2023).

This study focuses on the actions that should be taken to minimize observations encountered during SIRE VIQ Inspections. For analysis purposes VIQ inspection booklet has been examined as the inspection booklet itself is used as the main reference and guide for tanker inspections.

Literature Review

Although maritime inspections have been the subject of many studies, research for minimizing the SIRE VIQ inspection remarks seems to be not fully covered. As these inspections are of great importance for tanker companies and safety at sea, this study aims to fulfill this gap. The study presents the initial findings of postgraduate research on tanker SIRE VIQ inspections utilizing the fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) integrated with the fuzzy Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS). Both DEMATEL and TOPSIS methods are widely used in a variety of areas. Similar studies on tanker inspections are also of a wide range. Grbić et al.(2018) studied the current state of tanker inspections and possible improvement suggestions. They concluded that tankers worldwide are subject to various inspections and proposed that those inspections can be transformed into unified inspections with a new inspection regime. Also, Grbić et al.(2018) studied SIRE Inspections on tankers. They concluded that since maritime accidents involving tankers can have serious consequences, potential risks must be assessed to minimize risks, otherwise the safety of tankers could be compromised. In their study, Gurbuz and Celik conducted a case study on the maritime module-01, which was shown by a task-based risk assessment (TBRA) in the enclosed space entry procedure related to Gamified Mentoring Platform. As a result, Maritime Gentor has been conceptualized as a powerful training and mentoring platform for global transportation companies. Chen et al. (2019) observed the key factors that cause a vessel to be detained under nine categories during PSC Inspections between 2008 and 2017 refers to ISM deficiencies as the most significant common area for detention. As a different approach, Heij et al. (2011) examined the effects of inspection strategies on maritime safety and pollution prevention. Recent research using DEMATEL methods covers a variety of maritime-related topics. From the pollution aspect, Özdemir et al. (2016), by using the DEMATEL method, showed that from six predetermined factors, bunker operations and bilge waters are the substantial influential factor for pollution originating from ship operations. For evaluating gas-free related hazards, Akyüz and Çelik (2015) utilized the DEMATEL method to find “not blanking connections among the tanks when not in use” as the most significant operational hazard out of 18 critical operational hazards. Başhan and Demirel (2018), on the other hand, used the fuzzy DEMATEL approach to investigate 15 common critical problems of marine boilers faults and found that planned maintenance was vital for onboard boilers. Likewise, Balin et al. (2018) used the DEMATEL approach for marine diesel generators for critical operational faults. Their study determined 33 common faults that actually trigger each other, and the study concluded that timely maintenance was the key to solving the problem.

Multi-Criteria Decision Making (MCDM)

The fundamental hardship in decision-making comes from the fact that the problem at hand often bears complex, intertwined, and conflicting elements. In addition, there usually are numerous alternatives and evaluation criteria to choose from. The data to be processed may not always be clear-cut and complete. On top of that, the decision and the decision-making environment dynamically change. The psychological situation influences the decision maker, tendencies, and social status experience as the environment does by political and economic factors. A decision-making process starts first with identifying and defining the problem. After determining the options, evaluating, and analyzing the data/input, results must indicate the best available option. The whole process is verified by checking whether the chosen alternative achieves the desired results and goals (Ünal, 2011). MCDM, which is the examination of alternatives for decision-makers, helps to rank the alternatives according to their importance and facilitates the selection of the primary alternative in a given cluster (Jahanshahloovd et al., 2006). In the decision-making process, there should be more than one alternative or option to choose from, depending on the problem. In the application part, there may be more than one alternative, and criteria seem to be complicated and attached to the nature of the problem and, indeed, have a complex structure, overlapping or independent. The critical role of the criteria in this process is that they enable measuring the effectiveness of alternatives and are evaluation criteria consisting of the characteristics that will be taken as the base for the evaluation of alternatives which makes it necessary to make a detailed study when determining the criteria as it will directly affect the results. In other words, the criteria follow the standards and limits required for decision-making in the solution process. In the issues of MCDM, the examination of alternatives for decision makers, the ordering of the alternatives according to their importance, and the choice of the primary alternative are in question (Jahanshahloovd., 2006 et al.). MCDM with different models and features have been developed to analyse a structure consisting of many criteria (Özdemir and Güneroğlu, 2015).

Fuzzy Logic

Fuzzy MCDM can be defined as an approach used in multi-criteria decision problems in which decision-makers verbally express their judgments or cannot make objective judgments. Basically, the fuzzy logic method simplifies the verbal expression of uncertainties and the decision-making process, which is impossible to explain with precise expressions. After being coined by Asker

Zadeh in 1965, the approach has widely been admitted especially since the 1970s, and has been used in trade, management, medicine, mechatronics, and process and frequently implemented in many different areas and sectors such as control, engineering, and industry. From automatic steering systems to robotic doctors, from drones to self-parking in automobiles, it is possible to see fuzzy logic-based artificial intelligence systems at every point of life. Undoubtedly, fuzzy logic has a great place in the development and spread of these systems (Palit and Babuska, 2001; Nguyen, 2002 et al.; Chou, 2007; Cheng et al., 2008; Bulut, 2013). Fuzzy logic proposes real-life modeling and processing of non-numerical inputs; that is, the elements in the fuzzy set have membership degrees in the range [0,1] and their membership degrees show continuity in this range. Zadeh briefly explains this fuzzy logic and fuzzy sets system: “There is no such thing as precision. There is nothing absolutely certain" (Zadeh, 1965). According to classical theory, the membership degree of set elements is 1 if the element belongs to that set and 0 if not. This creates a very restrictive phenomenon. It does not use only certain expressions consisting of variables such as open-closed, hot-cold, 0-1. Based on this, it is understood that contrary to classical logic, fuzzy logic uses not only two-level but multi-level operations (Kosko et al., 1994; Chu and Lin, 2003; Cha and Yung, 2003). Contrary to classical models, which assume that the weights and degrees of the significance of the criteria are known precisely, fuzzy MCDM methods assume that the decision-making process is significantly affected by quantitative or qualitative criteria. Hence, Fuzzy MCDM methods provide effective results by quantifying inconclusive data as well as providing the opportunity to use verbal variables in evaluating criteria and alternatives.

Fuzzy set

A fuzzy set is a collection of elements with varying degrees of membership. It generalizes the concept of black-and-white dual membership in classical set theory to the concept of partial membership. Here, "0" indicates membership, "1" indicates full membership, and values between (0-1) correspond to the concept of partial membership (Altaş, 1999).

Fuzzy Numbers

Triangular fuzzy numbers are a special kind of fuzzy number described by three real numbers and expressed as (u, m, l). The parameters u, m, and l show the most significant possible, the most likely, and the smallest possible value, respectively. A graphic illustration of fuzzy numbers is shown in Figure 1 (Öztürk et al., 2008).

Fuzzy DEMATEL Method

The DEMATEL method is a notable and extensive method that creates temporary relationships between complex realities. This method is transcendent to other MCDM methods, such as AHP, as it considers the mutual relationships between the factors in the causal diagram thrown into the background in traditional techniques (Menteş et al., 2014). Although this method aims to put forward the cause-effect relationship between many factors that affect decision-making, it remains challenging to express the relation because not all criteria can be expressed quantitatively. This difficulty is eliminated by converting the criteria into fuzzy numbers after expert opinions, in other words, by moving the DEMATEL method into a fuzzy environment (Lin et al., 2008).

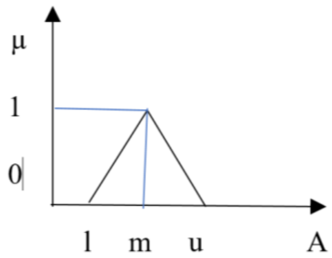

Fig. 1. Triangular fuzzy numbers (Öztürk et al., 2008)

Fuzzy TOPSIS Method

TOPSIS is a multi-criteria method to define the solutions of a finite series of alternatives based on the principle of the shortest distance from an ideal point simultaneously and the maximum distance from the farthest point. The method is also able to integrate the relative importance weights of the criteria (Olson, 2004). Within the Fuzzy TOPSIS method, uncertainty sourcing from the vagueness of linguistic variables used by the experts or decision-makers is eliminated by expanding these variables by using fuzzy sets (Chen, 2000). Hence, ranking the alternatives presents a more flexible method that deals with the criteria values of both qualitative and quantitative decision criteria. The fuzzy TOPSIS method provides a comparison environment by calculating the performances of the alternatives based on the existing criterion weights and by ranking the alternatives among themselves. When alternatives are ranked and listed among themselves, the ideal alternative is described as the closest to the positive ideal solution and the furthest to the negative ideal solution.

The Fuzzy TOPSIS method comes in handy in solving problems requiring group decisions, especially in processes with linguistic ambiguity. Decision-makers can quickly evaluate the importance of decision-making criteria and each alternative based on these decision criteria (Razmi et al., 2009).

Methodology

The primary approach of this research is that the best solution can be reached by prioritizing the requirements of SIRE VIQ-7 chapters using expert opinions and utilizing experts-proposed additional measures. The study follows a quantitative approach involving fuzzy logic perspective. The work is done based on multi-criteria decision-making tools. The analysis part starts by utilizing the fuzzy DEMATEL approach to classify the remarks/observations noted during the SIRE inspections. Further, the fuzzy TOPSIS method is used to sort solution suggestions offered for the most common observations. It is aimed to reach results by integrating the two methods so that a set of solution alternatives or a road map for minimizing the number of remarks in inspections is achieved. The process starts by determining the remark categories in accordance with the existing 12 chapters of the SIRE VIQ-7 document. The first step establishes the degree of importance attributed to the individual chapter by the opinions of area experts using the fuzzy DEMATEL approach. The experts gather the data through questionnaires and opinion forms voluntarily, either via electronic mail or hand delivery or by face-to-face interviews. The criteria listed in 12 available chapters of SIRE VIQ-7 are evaluated in a pairwise comparison technique with the inputs received from the stakeholders and representatives of the maritime sector. The evaluation obtained from fuzzy DEMATEL helped rank the SIRE VIQ-7 chapters' criterion weights and their degree of importance. The second area-expert team comprises masters, chief officers, and chief engineers with tanker experience. They are asked to produce criteria alternatives for predicting the best way to minimize the SIRE remarks. With the outcome of this part, ten alternatives are produced. In order to pinpoint the best alternative for minimizing SIRE VIQ remarks, the final phase of the study involved using fuzzy TOPSIS to calculate the distance of each alternative from the ideal solution; hence the best alternative is reached.

Results and Discussions

As the study involves subjective evaluations of different decision makers, two of the MCDM methods, Fuzzy DEMATEL integrated with Fuzzy TOPSIS, are used together to make the most common observation decisions and, as the best alternative proposal for the solution. The study presumes a relationship and connection between the criteria and the alternative solutions. For this reason, the DEMATEL approach was used to weigh the criteria with a stance that modelling with only a hierarchical approach would not be sufficient for a solution. However, when the relationships are evaluated directly by the decision makers, it is difficult to determine the cause-and-effect relationship of the criteria with the DEMATEL method. To overcome this problem, the study opted for fuzzy numbers using fuzzy sets for collected expert opinion. Thus, the ranking and weighting of the criteria by fuzzy DEMATEL according to their importance level were deemed more precise. The fuzzy TOPSIS method is used in the solution of alternatives to eliminate the ambiguity arising from the judgments of individuals while making group decisions. Table 1 shows that the SIRE VIQ-7 chapters were used to establish the criterion and Table 2 lists solution alternatives in the decision-making process within the study's conceptual model.

Table 1: Criteria Affecting the Inspector's Decision

CODE	*NAME OF CRITERION*
C1	General Information
C2	Certification and Documentation
C3	Crew Management
C4	Navigation & Communication
C5	Safety Management
C6	Pollution Prevention
C7	Maritime Security
C8	Cargo and Ballast Systems
C9	Mooring
C10	Engine and Steering Compartments
C11	General Appearance and Condition
C12	Ice Operations

Table 2: Alternatives

CODE	*NAME OF ALTERNATIVE*
A1	Increasing the Frequency of Audits & Pre-Inspections by the Company
A2	Pre-Inspections by Third Parties
A3	Employing Permanent Ship Crew
A4	Increasing Number of Ship Crew
A5	Employing Experienced Ship Crew
A6	Employing Experienced Office Crew
A7	Operating Low-Age Tanker
A8	Establishing New Training and Examination Program for Growing Accredited Masters, Officers, and Engineers By OCIMF
A9	Correct Implementation of Planned Maintenance System (PMS)
A10	Motivating Reward for Ship Crew as Per Inspection Result

Table 3: Information about Experts

Expert	Experiences
Expert 1	OCIMF-accredited SIRE Inspector
Expert 2	OCIMF-accredited SIRE Inspector
Expert 3	Academician (Assoc. Prof.Dr.- Tanker experienced)
Expert 4	Academician (Assoc. Prof.Dr.- Tanker experienced)
Expert 5	Academician (Asst. Prof. Dr.- Tanker experienced)
Expert 6	Vetting Department Manager
Expert 7	Master (15 years tanker experienced)
Expert 8	Master (12 years tanker experienced)
Expert 9	Chief Engineer (11 years tanker experienced)

Implementation of Fuzzy DEMATEL Method

The first 12 × 12 matrices are generated to determine the model of the correlations between the 12 criteria. The arithmetic mean of all the experts' opinions is used to generate the direct relation matrix z.

Table 4 indicates the Direct Relation Matrix, which is the same as the pairwise comparison matrix of the experts. Table 5 presents the Fuzzy normalized direct relation matrix. The fuzzy total relation matrixes are calculated below the formula, and Table 6 shows Fuzzy Total Relation Matrix. $\tilde{T} = \lim_{k \to +\infty} (\tilde{x}^1 \oplus \tilde{x}^2 \oplus \ldots \oplus \tilde{x}^k)$

Then defuzzification method was proposed (Opricovic and Tzeng, 2003). The steps of the method are as follows:

$$l_{ij}^n = \frac{\left(l_{ij}^t - \min l_{ij}^t\right)}{\Delta_{\min}^{\max}} \quad \text{(Eq.1)}$$

$$m_{ij}^n = \frac{\left(m_{ij}^t - \min l_{ij}^t\right)}{\Delta_{\min}^{\max}} \quad \text{(Eq.2)}$$

$$u_{ij}^n = \frac{\left(u_{ij}^t - \min l_{ij}^t\right)}{\Delta_{\min}^{\max}} \quad \text{(Eq.3)}$$

$$\Delta_{\min}^{\max} = \quad max u_{ij}^t - \min l_{ij}^t \quad \text{(Eq.4)}$$

defuzzified total relation matrix is presented in Table 7, and Table 8 shows calculated final output and causal relation diagram.

The causal diagram is constructed with (D+R) and (D-R) serving as the corresponding horizontal and vertical axes of the diagram. The values of (D+R) reflect the degree to which a factor is essential; therefore, the tankers that will undergo the inspections should pay more attention to these criteria. The values of (D-R) illustrate how much its impact extends. When the value of (D-R) is positive, the factor being considered belongs to the category of causes; when the value is negative, the factors being considered to belong to the category of effects. In this context, factors are evaluated according to table 8. (D + R) represents the degree of importance among factors in the system. As a result of the data obtained, it has been revealed that the most important criterion among the chapters of observations encountered in the SIRE VIQ inspections carried out on tankers is "Safety Management". C5 (Safety Management) is ranked in first place and C8, C4, C6, C3, C11, C10, C12, C7, C9, C2, and C1, are ranked in the next places. After "Safety Management", "Cargo and Ballast Systems", "Navigation & Communication", and "Pollution Prevention" choices are ranked 2nd, 3rd, and 4th.

(D-R) represents the degree of a factor's influence on the system. The criteria with a positive value (D-R) factor cause a group. In this study, when the criteria (D-R) are sorted according to the positive factor values, C5 (Safety Management) is ranked in the first place, and C6 > C4 > C3 > C8 > C10 > C11 and C2 are ranked in the following places. "Safety Management" with the highest positive (D - R) value is the criterion that impacts other criteria. Criteria with a negative (D-R) factor form an effective group. The criterion with a low (D - R) factor has a lower influence. In this study, when the criteria (D-R) were ranked among themselves according to the negative factor values, C7 > C9 > C12 and C1. General Information (C1) is ranked in the lowermost place. These criteria are those that are affected by other criteria. According to the results obtained in the study, C1 (General Information), with the lowest value (D - R), is the criterion most affected by the other criteria. The following figure 2 shows the model of significant relations.

All criteria are weighted using the formula of the equation. With the formula, the normalization process is performed for the weights of the factors. Table 9 shows the final outputs of the weight of Criterion.

$$W_i = \left\{\sqrt{(D_i + R_i)^2 + (D_i - R_i)^2}\right\} \quad \text{(Eq.5)}$$

$$W_i = \frac{w_i}{max_{1 \le i \le n}(w_i)} \forall i = 1,2, \ldots, n \quad \text{(Eq.6)}$$

Implementation of Fuzzy TOPSIS Method

Step 1: Alternatives are rated on several criteria, and the results of the decision matrix are shown in table 10.

Step 2: Create the normalized decision matrix. The normalized decision matrix, shown in table 11 (Chen's fuzzy TOPSIS method), is calculated based on the Positive Ideal Solution and Negative Ideal Solution.

Step 3: Create the weighted normalized decision matrix. The normalized decision matrix is multiplied by the weight of each criterion obtained by the fuzzy

Table 4: Direct Relation Matrix

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12
C 1	(0.000,0.000,0.000)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)	(0.000,0.000,0.250)
C 2	(0.750,1.000,1.000)	(0.000,0.000,0.000)	(0.139,0.389,0.639)	(0.250,0.500,0.750)	(0.194,0.444,0.694)	(0.222,0.472,0.694)	(0.306,0.556,0.778)	(0.333,0.583,0.806)	(0.250,0.500,0.722)	(0.222,0.472,0.722)	(0.306,0.556,0.778)	(0.278,0.528,0.778)
C 3	(0.750,1.000,1.000)	(0.306,0.556,0.806)	(0.000,0.000,0.000)	(0.389,0.639,0.889)	(0.278,0.528,0.750)	(0.389,0.639,0.889)	(0.333,0.583,0.806)	(0.306,0.556,0.806)	(0.389,0.639,0.861)	(0.361,0.611,0.861)	(0.389,0.639,0.833)	(0.306,0.556,0.778)
C 4	(0.750,1.000,1.000)	(0.361,0.611,0.833)	(0.417,0.667,0.861)	(0.000,0.000,0.000)	(0.194,0.444,0.667)	(0.278,0.528,0.778)	(0.389,0.639,0.833)	(0.444,0.694,0.889)	(0.472,0.722,0.972)	(0.333,0.583,0.806)	(0.417,0.667,0.861)	(0.389,0.639,0.861)
C 5	(0.750,1.000,1.000)	(0.444,0.694,0.861)	(0.583,0.833,0.944)	(0.556,0.806,0.944)	(0.000,0.000,0.000)	(0.500,0.750,0.944)	(0.528,0.778,0.944)	(0.556,0.806,0.944)	(0.528,0.778,0.972)	(0.500,0.750,0.889)	(0.472,0.722,0.861)	(0.556,0.806,0.944)
C 6	(0.750,1.000,1.000)	(0.361,0.611,0.833)	(0.472,0.722,0.944)	(0.361,0.583,0.833)	(0.222,0.472,0.722)	(0.000,0.000,0.000)	(0.333,0.583,0.806)	(0.389,0.639,0.861)	(0.417,0.639,0.833)	(0.389,0.639,0.889)	(0.361,0.611,0.833)	(0.417,0.667,0.861)
C 7	(0.750,1.000,1.000)	(0.306,0.556,0.806)	(0.250,0.500,0.750)	(0.139,0.389,0.639)	(0.250,0.500,0.750)	(0.194,0.444,0.694)	(0.000,0.000,0.000)	(0.194,0.444,0.694)	(0.278,0.528,0.778)	(0.250,0.500,0.722)	(0.250,0.500,0.750)	(0.250,0.500,0.722)
C 8	(0.750,1.000,1.000)	(0.361,0.611,0.833)	(0.361,0.611,0.833)	(0.361,0.611,0.833)	(0.194,0.444,0.694)	(0.389,0.639,0.833)	(0.417,0.667,0.861)	(0.000,0.000,0.000)	(0.389,0.639,0.861)	(0.389,0.639,0.889)	(0.417,0.667,0.861)	(0.417,0.667,0.833)
C 9	(0.750,1.000,1.000)	(0.250,0.500,0.750)	(0.139,0.389,0.639)	(0.222,0.472,0.722)	(0.111,0.361,0.611)	(0.250,0.500,0.750)	(0.278,0.528,0.778)	(0.222,0.472,0.694)	(0.000,0.000,0.000)	(0.222,0.472,0.722)	(0.222,0.472,0.722)	(0.361,0.611,0.861)
C10	(0.750,1.000,1.000)	(0.278,0.528,0.778)	(0.194,0.444,0.694)	(0.306,0.556,0.806)	(0.278,0.528,0.778)	(0.222,0.472,0.722)	(0.417,0.667,0.861)	(0.278,0.528,0.778)	(0.306,0.556,0.806)	(0.000,0.000,0.000)	(0.361,0.611,0.833)	(0.389,0.639,0.861)
C11	(0.750,1.000,1.000)	(0.194,0.444,0.694)	(0.278,0.528,0.778)	(0.250,0.500,0.750)	(0.194,0.444,0.694)	(0.278,0.528,0.778)	(0.333,0.583,0.778)	(0.361,0.611,0.833)	(0.417,0.667,0.889)	(0.278,0.528,0.778)	(0.000,0.000,0.000)	(0.389,0.639,0.861)
C12	(0.750,1.000,1.000)	(0.167,0.417,0.667)	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.278,0.528,0.778)	(0.278,0.528,0.750)	(0.250,0.500,0.750)	(0.194,0.444,0.694)	(0.139,0.389,0.639)	(0.222,0.472,0.722)	(0.222,0.472,0.722)	(0.000,0.000,0.000)

Table 5: Fuzzy Normalized Direct Relation Matrix

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12
C 1	(0.000,0.000,0.000)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)	(0.000,0.000,0.023)
C 2	(0.068,0.091,0.091)	(0.000,0.000,0.000)	(0.013,0.035,0.058)	(0.023,0.045,0.068)	(0.018,0.040,0.063)	(0.020,0.043,0.063)	(0.028,0.051,0.071)	(0.030,0.053,0.073)	(0.023,0.045,0.066)	(0.020,0.043,0.066)	(0.028,0.051,0.071)	(0.025,0.048,0.071)
C 3	(0.068,0.091,0.091)	(0.028,0.051,0.073)	(0.000,0.000,0.000)	(0.035,0.058,0.081)	(0.025,0.048,0.068)	(0.035,0.058,0.081)	(0.030,0.053,0.073)	(0.028,0.051,0.073)	(0.035,0.058,0.078)	(0.033,0.056,0.078)	(0.035,0.058,0.076)	(0.028,0.051,0.071)
C 4	(0.068,0.091,0.091)	(0.033,0.056,0.076)	(0.038,0.061,0.078)	(0.000,0.000,0.000)	(0.018,0.040,0.061)	(0.025,0.048,0.071)	(0.035,0.058,0.076)	(0.040,0.063,0.081)	(0.043,0.066,0.088)	(0.030,0.053,0.073)	(0.038,0.061,0.078)	(0.035,0.058,0.078)
C 5	(0.068,0.091,0.091)	(0.040,0.063,0.078)	(0.053,0.076,0.086)	(0.051,0.073,0.086)	(0.000,0.000,0.000)	(0.045,0.068,0.086)	(0.048,0.071,0.086)	(0.051,0.073,0.086)	(0.048,0.071,0.088)	(0.045,0.068,0.081)	(0.043,0.066,0.078)	(0.051,0.073,0.086)
C 6	(0.068,0.091,0.091)	(0.033,0.056,0.076)	(0.043,0.066,0.086)	(0.033,0.053,0.076)	(0.020,0.043,0.066)	(0.000,0.000,0.000)	(0.030,0.053,0.073)	(0.035,0.058,0.078)	(0.038,0.058,0.076)	(0.035,0.058,0.081)	(0.033,0.056,0.076)	(0.038,0.061,0.078)
C 7	(0.068,0.091,0.091)	(0.028,0.051,0.073)	(0.023,0.045,0.068)	(0.013,0.035,0.058)	(0.023,0.045,0.068)	(0.018,0.040,0.063)	(0.000,0.000,0.000)	(0.018,0.040,0.063)	(0.025,0.048,0.071)	(0.023,0.045,0.066)	(0.023,0.045,0.068)	(0.023,0.045,0.066)
C 8	(0.068,0.091,0.091)	(0.033,0.056,0.076)	(0.033,0.056,0.076)	(0.033,0.056,0.076)	(0.018,0.040,0.063)	(0.035,0.058,0.076)	(0.038,0.061,0.078)	(0.000,0.000,0.000)	(0.035,0.058,0.078)	(0.035,0.058,0.081)	(0.038,0.061,0.078)	(0.038,0.061,0.076)
C 9	(0.068,0.091,0.091)	(0.023,0.045,0.068)	(0.013,0.035,0.058)	(0.020,0.043,0.066)	(0.010,0.033,0.056)	(0.023,0.045,0.068)	(0.025,0.048,0.071)	(0.020,0.043,0.063)	(0.000,0.000,0.000)	(0.020,0.043,0.066)	(0.020,0.043,0.066)	(0.033,0.056,0.078)
C10	(0.068,0.091,0.091)	(0.025,0.048,0.071)	(0.018,0.040,0.063)	(0.028,0.051,0.073)	(0.025,0.048,0.071)	(0.020,0.043,0.066)	(0.038,0.061,0.078)	(0.025,0.048,0.071)	(0.028,0.051,0.073)	(0.000,0.000,0.000)	(0.033,0.056,0.076)	(0.035,0.058,0.078)
C11	(0.068,0.091,0.091)	(0.018,0.040,0.063)	(0.025,0.048,0.071)	(0.023,0.045,0.068)	(0.018,0.040,0.063)	(0.025,0.048,0.071)	(0.030,0.053,0.071)	(0.033,0.056,0.076)	(0.038,0.061,0.081)	(0.025,0.048,0.071)	(0.000,0.000,0.000)	(0.035,0.058,0.078)
C12	(0.068,0.091,0.091)	(0.015,0.038,0.061)	(0.023,0.045,0.068)	(0.023,0.045,0.068)	(0.025,0.048,0.071)	(0.025,0.048,0.068)	(0.023,0.045,0.068)	(0.018,0.040,0.063)	(0.013,0.035,0.058)	(0.020,0.043,0.066)	(0.020,0.043,0.066)	(0.000,0.000,0.000)

Table 6: The Fuzzy Total Relation Matrix

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12
C 1	(0.000,0.000,0.089)	(0.000,0.000,0.088)	(0.000,0.000,0.088)	(0.000,0.000,0.089)	(0.000,0.000,0.083)	(0.000,0.000,0.088)	(0.000,0.000,0.091)	(0.000,0.000,0.089)	(0.000,0.000,0.092)	(0.000,0.000,0.089)	(0.000,0.000,0.090)	(0.000,0.000,0.092)
C 2	(0.090,0.176,0.338)	(0.008,0.045,0.188)	(0.021,0.079,0.243)	(0.031,0.088,0.253)	(0.024,0.077,0.232)	(0.028,0.086,0.247)	(0.037,0.097,0.262)	(0.038,0.097,0.259)	(0.032,0.092,0.260)	(0.029,0.087,0.253)	(0.036,0.096,0.259)	(0.035,0.096,0.265)
C 3	(0.098,0.192,0.366)	(0.039,0.101,0.278)	(0.012,0.053,0.209)	(0.046,0.108,0.285)	(0.033,0.091,0.256)	(0.046,0.107,0.283)	(0.043,0.108,0.286)	(0.040,0.103,0.281)	(0.048,0.113,0.293)	(0.044,0.107,0.285)	(0.047,0.111,0.285)	(0.041,0.108,0.288)
C 4	(0.100,0.195,0.368)	(0.044,0.107,0.281)	(0.049,0.112,0.282)	(0.012,0.055,0.212)	(0.026,0.086,0.251)	(0.037,0.100,0.276)	(0.048,0.115,0.289)	(0.052,0.116,0.288)	(0.056,0.121,0.303)	(0.042,0.106,0.282)	(0.050,0.115,0.288)	(0.049,0.116,0.295)
C 5	(0.113,0.220,0.395)	(0.056,0.127,0.304)	(0.068,0.139,0.309)	(0.066,0.136,0.312)	(0.013,0.058,0.212)	(0.061,0.131,0.310)	(0.066,0.140,0.319)	(0.067,0.139,0.314)	(0.066,0.140,0.325)	(0.062,0.133,0.310)	(0.061,0.134,0.309)	(0.070,0.145,0.324)
C 6	(0.100,0.195,0.370)	(0.044,0.107,0.283)	(0.054,0.116,0.291)	(0.044,0.105,0.284)	(0.029,0.088,0.257)	(0.012,0.054,0.212)	(0.044,0.110,0.289)	(0.047,0.111,0.288)	(0.051,0.114,0.294)	(0.047,0.111,0.291)	(0.046,0.111,0.288)	(0.052,0.118,0.297)
C 7	(0.089,0.174,0.337)	(0.035,0.092,0.255)	(0.030,0.087,0.250)	(0.021,0.078,0.243)	(0.028,0.081,0.236)	(0.025,0.082,0.246)	(0.009,0.048,0.194)	(0.026,0.084,0.249)	(0.034,0.093,0.263)	(0.030,0.088,0.252)	(0.031,0.090,0.255)	(0.032,0.092,0.259)
C 8	(0.100,0.195,0.367)	(0.044,0.107,0.281)	(0.044,0.107,0.280)	(0.044,0.107,0.282)	(0.026,0.086,0.252)	(0.046,0.109,0.280)	(0.051,0.117,0.291)	(0.013,0.057,0.213)	(0.048,0.114,0.294)	(0.047,0.111,0.288)	(0.050,0.115,0.287)	(0.052,0.119,0.293)
C 9	(0.088,0.172,0.334)	(0.030,0.086,0.249)	(0.020,0.077,0.239)	(0.027,0.084,0.248)	(0.016,0.069,0.223)	(0.030,0.086,0.248)	(0.033,0.092,0.258)	(0.028,0.085,0.247)	(0.009,0.046,0.195)	(0.027,0.085,0.250)	(0.028,0.086,0.251)	(0.041,0.100,0.268)
C10	(0.094,0.185,0.355)	(0.035,0.095,0.267)	(0.028,0.088,0.259)	(0.037,0.097,0.270)	(0.032,0.088,0.251)	(0.030,0.090,0.262)	(0.049,0.111,0.281)	(0.035,0.097,0.270)	(0.039,0.102,0.280)	(0.010,0.050,0.204)	(0.043,0.105,0.276)	(0.047,0.110,0.285)
C11	(0.094,0.184,0.352)	(0.027,0.087,0.258)	(0.034,0.095,0.264)	(0.032,0.092,0.264)	(0.025,0.081,0.242)	(0.034,0.094,0.264)	(0.041,0.104,0.273)	(0.042,0.103,0.272)	(0.048,0.110,0.284)	(0.035,0.095,0.268)	(0.011,0.052,0.203)	(0.046,0.110,0.283)
C12	(0.088,0.173,0.335)	(0.023,0.080,0.243)	(0.030,0.087,0.249)	(0.030,0.087,0.251)	(0.030,0.083,0.237)	(0.032,0.089,0.249)	(0.031,0.091,0.257)	(0.026,0.084,0.248)	(0.022,0.081,0.251)	(0.028,0.085,0.250)	(0.029,0.087,0.251)	(0.010,0.048,0.196)

Table 7: Defuzzified Total Relation Matrix

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12
C 1	0.011	0.013	0.012	0.013	0.012	0.012	0.013	0.013	0.013	0.013	0.013	0.013
C 2	0.191	0.069	0.103	0.112	0.099	0.109	0.12	0.119	0.116	0.111	0.118	0.12
C 3	0.206	0.125	0.079	0.131	0.112	0.131	0.132	0.127	0.136	0.13	0.133	0.131
C 4	0.209	0.13	0.134	0.08	0.107	0.124	0.137	0.138	0.144	0.129	0.137	0.139
C 5	0.229	0.147	0.157	0.155	0.082	0.151	0.159	0.157	0.16	0.152	0.152	0.163
C 6	0.209	0.13	0.138	0.129	0.11	0.08	0.133	0.134	0.138	0.134	0.133	0.141
C 7	0.19	0.115	0.111	0.102	0.102	0.106	0.072	0.108	0.118	0.111	0.113	0.116
C 8	0.208	0.129	0.13	0.13	0.107	0.131	0.139	0.082	0.138	0.134	0.137	0.14
C 9	0.188	0.109	0.101	0.108	0.091	0.109	0.116	0.109	0.071	0.109	0.11	0.124
C 10	0.2	0.119	0.112	0.121	0.109	0.114	0.133	0.121	0.126	0.076	0.128	0.133
C 11	0.199	0.111	0.118	0.116	0.102	0.118	0.126	0.126	0.134	0.119	0.077	0.133
C 12	0.188	0.104	0.11	0.11	0.104	0.112	0.114	0.108	0.106	0.109	0.111	0.073

Table 8: The Final Output

	R	D	D+R	Rank of D+R	D-R	Rank of D-R	Group
C1 (General Information)	2,227	0,151	2,378	12	-2,076	12	Effect
C2 (Certification & Documentation)	1,299	1,386	2,685	11	0,087	8	Cause
C3 (Crew Management)	1,305	1,573	2,878	5	0,268	4	Cause
C4 (Navigation & Communication)	1,308	1,606	2,914	3	0,298	3	Cause
C5 (Safety Management)	1,136	1,865	3,001	1	0,729	1	Cause
C6 (Pollution Prevention)	1,297	1,609	2,906	4	0,312	2	Cause
C7 (Maritime Security)	1,394	1,364	2,758	9	-0,030	9	Effect
C8 (Cargo & Ballast System)	1,341	1,605	2,946	2	0,264	5	Cause
C9 (Mooring)	1,400	1,344	2,744	10	-0,056	10	Effect
C10 (Engine&Steering Compartments)	1,326	1,492	2,818	7	0,166	6	Cause
C11 (General Appearance & Condition)	1,361	1,479	2,840	6	0,118	7	Cause
C12 (Ice Operations)	1,427	1,349	2,776	8	-0,078	11	Effect

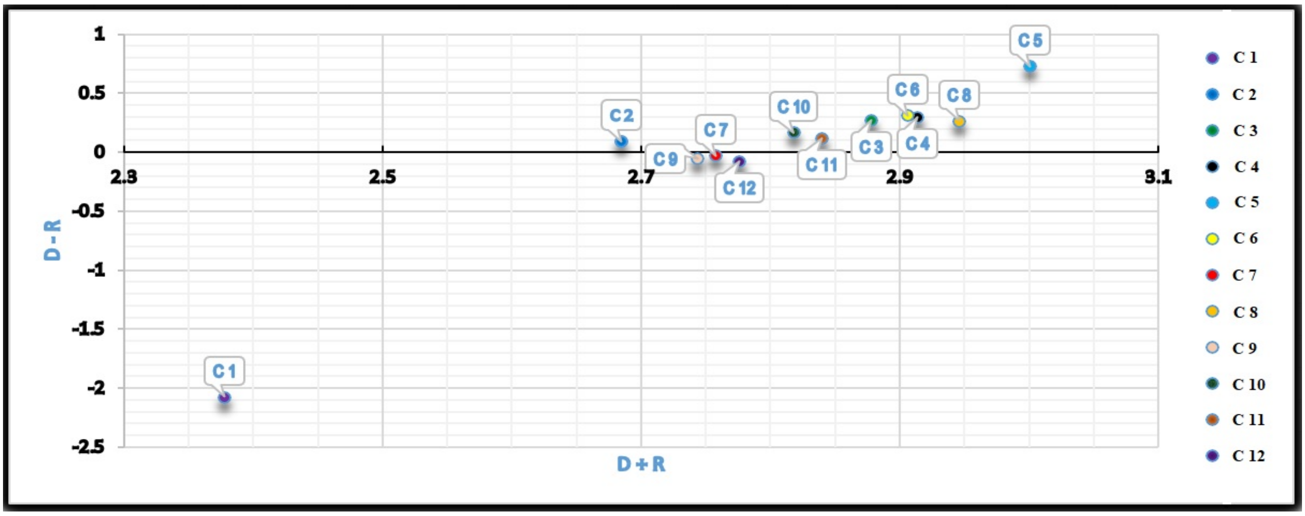

Fig. 2: Cause-Effect Diagram

Table 9: Weight of Criterion

CRITERIA	Weight
C1 (General Information)	**0,091**
C2 (Certification & Documentation)	**0,078**
C3 (Crew Management)	**0,084**
C4 (Navigation & Communication)	**0,085**
C5 (Safety Management)	**0,089**
C6 (Pollution Prevention)	**0,085**
C7 (Maritime Security)	**0,080**
C8 (Cargo & Ballast System)	**0,086**
C9 (Mooring)	**0,079**
C10 (Engine & Steering Compartments)	**0,082**
C11 (General Appearance & Condition)	**0,082**
C12 (Ice Operations)	**0,080**

Table 10. Decision Matrix

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12
A 1	(0.000,0.000,0.250)	(0.528,0.778,0.944)	(0.444,0.694,0.889)	(0.611,0.861,1.000)	(0.611,0.861,0.944)	(0.500,0.750,0.944)	(0.361,0.611,0.861)	(0.500,0.750,0.917)	(0.472,0.722,0.917)	(0.500,0.750,0.917)	(0.556,0.806,0.972)	(0.222,0.472,0.722)
A 2	(0.000,0.000,0.250)	(0.583,0.833,0.972)	(0.417,0.667,0.861)	(0.667,0.917,1.000)	(0.583,0.833,0.972)	(0.556,0.806,0.972)	(0.472,0.722,0.944)	(0.611,0.861,0.972)	(0.583,0.833,0.944)	(0.583,0.833,1.000)	(0.528,0.778,0.972)	(0.389,0.639,0.861)
A 3	(0.000,0.000,0.250)	(0.333,0.583,0.806)	(0.528,0.778,0.944)	(0.389,0.639,0.861)	(0.611,0.861,0.944)	(0.361,0.611,0.861)	(0.444,0.694,0.944)	(0.611,0.861,0.944)	(0.417,0.667,0.917)	(0.556,0.806,0.972)	(0.500,0.750,0.917)	(0.222,0.472,0.722)
A 4	(0.000,0.000,0.250)	(0.250,0.500,0.750)	(0.389,0.639,0.861)	(0.611,0.861,0.944)	(0.611,0.861,0.944)	(0.472,0.722,0.889)	(0.361,0.611,0.806)	(0.583,0.833,0.944)	(0.583,0.833,0.944)	(0.583,0.833,0.944)	(0.472,0.722,0.917)	(0.139,0.389,0.639)
A 5	(0.000,0.000,0.250)	(0.472,0.722,0.917)	(0.611,0.861,1.000)	(0.556,0.806,0.917)	(0.639,0.889,0.972)	(0.667,0.917,0.972)	(0.444,0.694,0.917)	(0.583,0.833,0.944)	(0.611,0.861,0.972)	(0.667,0.917,1.000)	(0.528,0.778,0.972)	(0.389,0.639,0.861)
A 6	(0.000,0.000,0.250)	(0.444,0.694,0.889)	(0.583,0.833,0.972)	(0.472,0.722,0.861)	(0.639,0.889,1.000)	(0.528,0.778,0.917)	(0.500,0.750,0.944)	(0.556,0.806,0.944)	(0.556,0.806,0.917)	(0.472,0.722,0.889)	(0.417,0.667,0.889)	(0.417,0.667,0.889)
A 7	(0.000,0.000,0.250)	(0.250,0.500,0.694)	(0.194,0.444,0.694)	(0.472,0.722,0.944)	(0.472,0.722,0.889)	(0.611,0.861,0.944)	(0.333,0.583,0.833)	(0.611,0.861,0.972)	(0.472,0.722,0.917)	(0.583,0.833,0.972)	(0.694,0.944,1.000)	(0.389,0.639,0.861)
A 8	(0.000,0.000,0.250)	(0.333,0.583,0.833)	(0.500,0.750,0.944)	(0.611,0.861,0.972)	(0.694,0.944,1.000)	(0.611,0.861,1.000)	(0.444,0.694,0.917)	(0.611,0.861,0.972)	(0.444,0.694,0.917)	(0.500,0.750,0.944)	(0.250,0.500,0.722)	(0.361,0.611,0.833)
A 9	(0.000,0.000,0.250)	(0.444,0.694,0.889)	(0.306,0.556,0.778)	(0.500,0.750,0.917)	(0.556,0.806,0.944)	(0.472,0.722,0.944)	(0.306,0.556,0.806)	(0.667,0.917,1.000)	(0.583,0.833,0.972)	(0.583,0.833,0.972)	(0.500,0.750,0.944)	(0.250,0.500,0.750)
A10	(0.000,0.000,0.250)	(0.250,0.500,0.750)	(0.417,0.667,0.889)	(0.361,0.611,0.833)	(0.389,0.639,0.861)	(0.222,0.472,0.722)	(0.306,0.556,0.778)	(0.278,0.528,0.778)	(0.278,0.528,0.750)	(0.278,0.528,0.778)	(0.472,0.722,0.917)	(0.139,0.389,0.639)

Table. 11. Normalized Decision Matrix

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12
A1	(0.000,0.000,1.000)	(0.543,0.800,0.971)	(0.444,0.694,0.889)	(0.611,0.861,1.000)	(0.611,0.861,0.944)	(0.500,0.750,0.944)	(0.382,0.647,0.912)	(0.500,0.750,0.917)	(0.486,0.743,0.943)	(0.500,0.750,0.917)	(0.556,0.806,0.972)	(0.250,0.531,0.812)
A2	(0.000,0.000,1.000)	(0.600,0.857,1.000)	(0.417,0.667,0.861)	(0.667,0.917,1.000)	(0.583,0.833,0.972)	(0.556,0.806,0.972)	(0.500,0.765,1.000)	(0.611,0.861,0.972)	(0.600,0.857,0.971)	(0.583,0.833,1.000)	(0.528,0.778,0.972)	(0.438,0.719,0.969)
A3	(0.000,0.000,1.000)	(0.343,0.600,0.829)	(0.528,0.778,0.944)	(0.389,0.639,0.861)	(0.611,0.861,0.944)	(0.361,0.611,0.861)	(0.470,0.735,1.000)	(0.611,0.861,0.944)	(0.429,0.686,0.943)	(0.556,0.806,0.972)	(0.500,0.750,0.917)	(0.250,0.531,0.812)
A4	(0.000,0.000,1.000)	(0.257,0.514,0.772)	(0.389,0.639,0.861)	(0.611,0.861,0.944)	(0.611,0.861,0.944)	(0.472,0.722,0.889)	(0.382,0.647,0.854)	(0.583,0.833,0.944)	0.600,0.857,0.971)	(0.583,0.833,0.944)	(0.472,0.722,0.917)	(0.156,0.438,0.719)
A5	(0.000,0.000,1.000)	(0.486,0.743,0.943)	(0.611,0.861,1.000)	(0.556,0.806,0.917)	(0.639,0.889,0.972)	(0.667,0.917,0.972)	(0.470,0.735,0.971)	(0.583,0.833,0.944)	(0.629,0.886,1.000)	(0.667,0.917,1.000)	(0.528,0.778,0.972)	(0.438,0.719,0.969)
A6	(0.000,0.000,1.000)	(0.457,0.714,0.915)	(0.583,0.833,0.972)	(0.472,0.722,0.861)	(0.639,0.889,1.000)	(0.528,0.778,0.917)	(0.530,0.794,1.000)	(0.556,0.806,0.944)	(0.572,0.829,0.943)	(0.472,0.722,0.889)	(0.417,0.667,0.889)	(0.469,0.750,1.000)
A7	(0.000,0.000,1.000)	(0.257,0.514,0.714)	(0.194,0.444,0.694)	(0.472,0.722,0.944)	(0.472,0.722,0.889)	(0.611,0.861,0.944)	(0.353,0.618,0.882)	(0.611,0.861,0.972)	(0.486,0.743,0.943)	(0.583,0.833,0.972)	(0.694,0.944,1.000)	(0.438,0.719,0.969)
A8	(0.000,0.000,1.000)	(0.343,0.600,0.857)	(0.500,0.750,0.944)	(0.611,0.861,0.972)	(0.694,0.944,1.000)	(0.611,0.861,1.000)	(0.470,0.735,0.971)	(0.611,0.861,0.972)	(0.457,0.714,0.943)	(0.500,0.750,0.944)	(0.250,0.500,0.722)	(0.406,0.687,0.937)
A9	(0.000,0.000,1.000)	(0.457,0.714,0.915)	(0.306,0.556,0.778)	(0.500,0.750,0.917)	(0.556,0.806,0.944)	(0.472,0.722,0.944)	(0.324,0.589,0.854)	(0.667,0.917,1.000)	(0.600,0.857,1.000)	(0.583,0.833,0.972)	(0.500,0.750,0.944)	(0.281,0.562,0.844)
A10	(0.000,0.000,1.000)	(0.257,0.514,0.772)	(0.417,0.667,0.889)	(0.361,0.611,0.833)	(0.389,0.639,0.861)	(0.222,0.472,0.722)	(0.324,0.589,0.824)	(0.278,0.528,0.778)	(0.286,0.543,0.772)	(0.278,0.528,0.778)	(0.472,0.722,0.917)	(0.156,0.438,0.719)

Table 12. Weighted Normalized Decision Matrix

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12
A 1	(0.000,0.000,0.091)	(0.042,0.062,0.076)	(0.037,0.058,0.075)	(0.052,0.073,0.085)	(0.054,0.077,0.084)	(0.043,0.064,0.080)	(0.031,0.052,0.073)	(0.043,0.065,0.079)	(0.038,0.059,0.075)	(0.041,0.062,0.075)	(0.046,0.066,0.080)	(0.020,0.042,0.065)
A 2	(0.000,0.000,0.091)	(0.047,0.067,0.078)	(0.035,0.056,0.072)	(0.057,0.078,0.085)	(0.052,0.074,0.087)	(0.047,0.069,0.083)	(0.040,0.061,0.080)	(0.053,0.074,0.084)	(0.047,0.068,0.077)	(0.048,0.068,0.082)	(0.043,0.064,0.080)	(0.035,0.058,0.077)
A 3	(0.000,0.000,0.091)	(0.027,0.047,0.065)	(0.044,0.065,0.079)	(0.033,0.054,0.073)	(0.054,0.077,0.084)	(0.031,0.052,0.073)	(0.038,0.059,0.080)	(0.053,0.074,0.081)	(0.034,0.054,0.075)	(0.046,0.066,0.080)	(0.041,0.062,0.075)	(0.020,0.042,0.065)
A 4	(0.000,0.000,0.091)	(0.020,0.040,0.060)	(0.030,0.051,0.070)	(0.052,0.073,0.080)	(0.054,0.077,0.084)	(0.040,0.061,0.076)	(0.031,0.052,0.068)	(0.050,0.072,0.081)	(0.047,0.068,0.077)	(0.048,0.068,0.077)	(0.039,0.059,0.075)	(0.013,0.035,0.058)
A 5	(0.000,0.000,0.091)	(0.038,0.058,0.074)	(0.051,0.072,0.084)	(0.047,0.069,0.078)	(0.057,0.079,0.087)	(0.057,0.078,0.083)	(0.038,0.059,0.078)	(0.050,0.072,0.081)	(0.050,0.070,0.079)	(0.055,0.075,0.082)	(0.043,0.064,0.080)	(0.035,0.058,0.077)
A 6	(0.000,0.000,0.091)	(0.036,0.056,0.071)	(0.049,0.070,0.082)	(0.040,0.061,0.073)	(0.057,0.079,0.089)	(0.045,0.066,0.078)	(0.042,0.064,0.080)	(0.048,0.069,0.081)	(0.045,0.066,0.075)	(0.039,0.059,0.073)	(0.034,0.055,0.073)	(0.038,0.060,0.080)
A 7	(0.000,0.000,0.091)	(0.020,0.040,0.056)	(0.016,0.037,0.058)	(0.040,0.061,0.080)	(0.042,0.064,0.079)	(0.052,0.073,0.080)	(0.028,0.049,0.071)	(0.053,0.074,0.084)	(0.038,0.059,0.075)	(0.048,0.068,0.080)	(0.057,0.077,0.082)	(0.035,0.058,0.077)
A 8	(0.000,0.000,0.091)	(0.027,0.047,0.067)	(0.042,0.063,0.079)	(0.052,0.073,0.083)	(0.062,0.084,0.089)	(0.052,0.073,0.085)	(0.038,0.059,0.078)	(0.053,0.074,0.084)	(0.036,0.056,0.075)	(0.041,0.062,0.077)	(0.021,0.041,0.059)	(0.032,0.055,0.075)
A 9	(0.000,0.000,0.091)	(0.036,0.056,0.071)	(0.026,0.047,0.065)	(0.043,0.064,0.078)	(0.049,0.072,0.084)	(0.040,0.061,0.080)	(0.026,0.047,0.068)	(0.057,0.079,0.086)	(0.047,0.068,0.079)	(0.048,0.068,0.080)	(0.041,0.062,0.077)	(0.022,0.045,0.067)
A 10	(0.000,0.000,0.091)	(0.020,0.040,0.060)	(0.035,0.056,0.075)	(0.031,0.052,0.071)	(0.035,0.057,0.077)	(0.019,0.040,0.061)	(0.026,0.047,0.066)	(0.024,0.045,0.067)	(0.023,0.043,0.061)	(0.023,0.043,0.064)	(0.039,0.059,0.075)	(0.013,0.035,0.058)

Table 13: FPIS and FNIS

	FPIS	FNIS
C 1	(0.000,0.000,0.091)	(0.000,0.000,0.091)
C 2	(0.047,0.067,0.078)	(0.020,0.040,0.056)
C 3	(0.051,0.072,0.084)	(0.016,0.037,0.058)
C 4	(0.057,0.078,0.085)	(0.031,0.052,0.071)
C 5	(0.062,0.084,0.089)	(0.035,0.057,0.077)
C 6	(0.057,0.078,0.085)	(0.019,0.040,0.061)
C 7	(0.042,0.064,0.080)	(0.026,0.047,0.066)
C 8	(0.057,0.079,0.086)	(0.024,0.045,0.067)
C 9	(0.050,0.070,0.079)	(0.023,0.043,0.061)
C 10	(0.055,0.075,0.082)	(0.023,0.043,0.064)
C 11	(0.057,0.077,0.082)	(0.021,0.041,0.059)
C 12	(0.038,0.060,0.080)	(0.013,0.035,0.058)

Table 14: Distance from FPIS and FNIS

	Distance from FPIS	Distance from FNIS
A 1	0.109	0.184
A 2	0.059	0.235
A 3	0.134	0.161
A 4	0.135	0.159
A 5	0.046	0.247
A 6	0.088	0.205
A 7	0.128	0.165
A 8	0.102	0.191
A 9	0.12	0.174
A 10	0.256	0.038

Table 15: Closeness Coefficient

	Ci	Rank
A 1	0.628	5
A 2	0.8	2
A 3	0.547	8
A 4	0.539	9
A 5	0.842	1
A 6	0.7	3
A 7	0.563	7
A 8	0.651	4
A 9	0.591	6
A 10	0.13	10

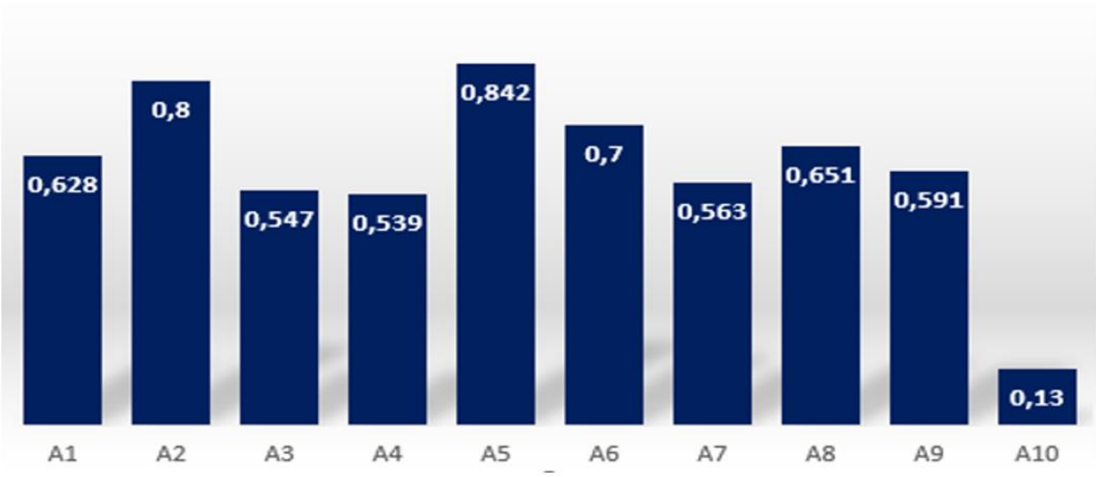

Fig. 3: The closeness coefficient of each alternative

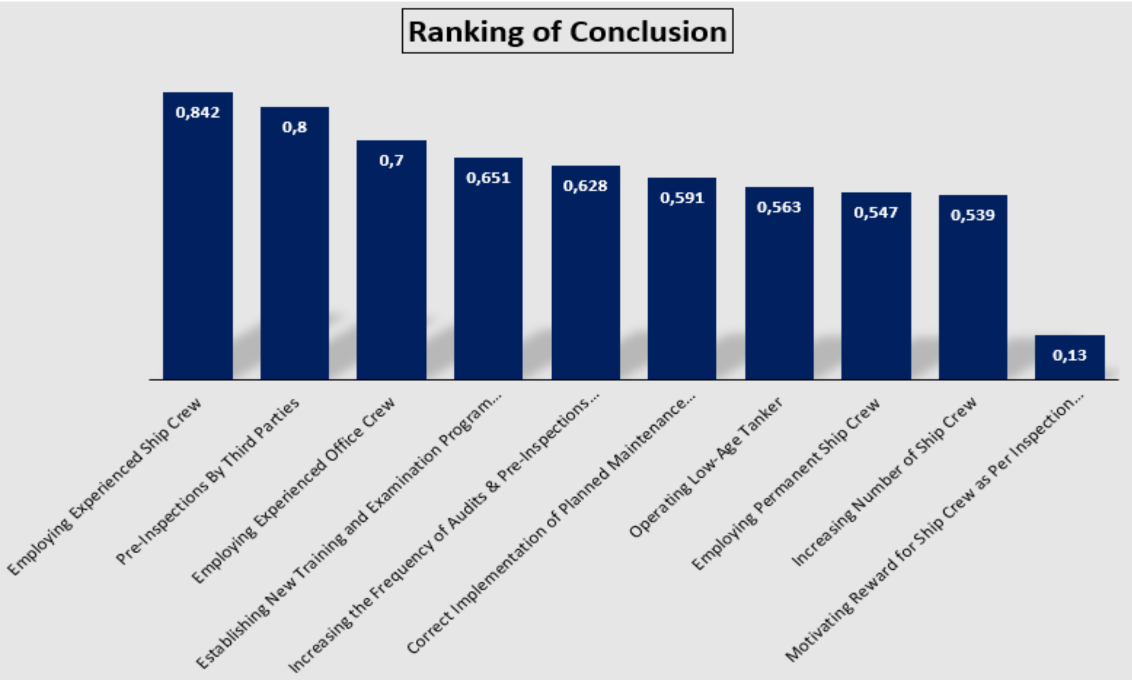

Figure 4: Ranking of Conclusion.

DEMATEL method, and the weighted normalized decision matrix, shown in table 12, is calculated.

Step 4: Determine the Fuzzy Positive Ideal Solution (FPIS, A*) and the Fuzzy Negative Ideal Solution (FPIS,, A^{-}). The positive and negative ideal solutions are shown in table 13 below.

Step 5: Calculate the distance FPIS A* and FNIS A^{-}**.** Table 14 shows the distance from FPIS and FNIS.

Step 6: Calculate the closeness coefficient CC_i and rank the alternatives. The best alternative is closest to the FPIS and farthest to the FNIS. The closeness coefficient of each alternative and its ranking order of it are shown in table 15.

When ordering the closeness coefficients of the alternatives according to Figure 3 in descending order, it is output as A5> A2> A6> A8> A1> A9> A7> A3> A4> A10 ranking of conclusion.

Conclusion

The globalization of the world market creates a competitive environment with a number of competitive factors that are directly affected by the interactions in all markets. Tanker transportation must be carried out in a safe and reliable manner to ensure the safety of human life, and not harm the environment. To ensure this, regular Flag State and Port State Inspections and additional inspection tools such as SIRE VIQ inspections are very useful. Tanker transportation is almost at the center of global competition since the transported cargo is dangerous goods, and the outcomes of the inspections can be effective in commercial and/or legal matters. Tankers must satisfactorily end these inspections in order to continue their commercial operations. In this study, the SIRE VIQ inspection was examined in order to determine the most effective method to reduce the number of observations, considering that observations may have economic consequences. The focus is on the VIQ sections that inspector really use as a guide when conducting and issuing SIRE inspections. Current research has revealed that using two- or three-dimensional matrices makes it impossible to arrive at the optimal answer owing to the complexity of inspection criteria. The study chooses to use the multi-criteria decision-making methodology because mathematical MCDM approaches provide more accurate results.

In this study, benefiting from the valuable evaluations and expertise of the tanker crew and inspectors, a quantitative method is introduced. This method provides an approach for minimizing the most observed remarks of SIRE VIQ inspections. Although there are many studies in the literature, mostly with the AHP approach, to weigh and rank the criteria according to their importance, there is a relationship and connection between the criteria and alternative solutions. In light of the fact that modeling based only on a hierarchical approach would not be enough to find a solution, this research used the DEMATEL technique to evaluate many criteria. However, when relations are examined directly by decision-makers, it is difficult to identify the cause-and-effect connection of criteria using the DEMATEL technique. In order to solve this problem, it was preferred to give fuzzy numbers to the expert opinions collected by using a fuzzy set. The analysis also included expert opinions by treating them as a single group, as explained in the methodology. Because of this, it was decided that the fuzzy DEMATEL method of rating and weighting the criteria according to their relevance levels would be the most accurate.

In the next step, It was decided to determine the best alternative by ranking the alternatives created in order to reduce the observations with the TOPSIS method. This method also had the benefits of giving a quick answer and figuring out how far away the best answer. However, the Fuzzy TOPSIS method is used to solve the options to get rid of the vagueness that comes from relying on the opinions of individuals when making group decisions.

The results achieved by applying these methods in an appropriate sequence are shown in Figure 4.

As a result of the study, some factors that are effective in tanker operations were evaluated by the experts, and "Employing Experienced Ship Crew" became the most important factor. “Pre-Inspections By Third Parties” and “Employing Experienced Office Crew” rank second and third. As it is clearly seen, having expertise in the field and regular inspections have vital importance in tanker operations. On the other hand, it is understood that “8. Employing Permanent Ship Crew”, “9. Increasing Number of Ship Crew”, and “10. Motivating Reward for Ship Crew as Per Inspection Result” are the least effective factors.

In addition to prioritizing SIRE VIQ chapters, another significant conclusion of the study is that the experts ranked the alternative "Establishing New Training and Examination Program for Growing Accredited Masters, Officers and Engineers by OCIMF" fourth. This alternative has the potential to move tanker inspections forward by one step in the not-too-distant future.
The integrated method applied in this study may create a possibility to minimize the detected observations by putting forward the order of importance of different alternatives determined to reduce observations in SIRE inspections. Thus, safety will be maximized on the tankers passing through inspection successfully.

Acknowledgements
In the preparation of this study, Piri Reis University Maritime Faculty member Asst.Prof.Dr. Aydın Şıhmantepe has made valuable contributions. We dedicate our article to the cherished memory of our dear teacher, who unfortunately lost his life at an early age.

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ANNEX 1: Tseng's Fuzzy DEMATEL method Application to the Study

In this study, Tseng's (2009) Fuzzy DEMATEL method was applied in the following steps.

DEMATEL Step 1: Determining the decision goal and creating an expert group to tackle the issue.

DEMATEL Step 2: Determination of the Criteria and fuzzy evaluation scale creation

Decision-making groups were constituted of specialists. In developing the criteria, approaches such as literature review, expert opinions, or market research are employed. After forming the decision-making expert group, the linguistic factors in Table 16 were employed to elicit expert judgments for comparing these criteria and alternatives and evaluating them pairwise (Tseng, 2009).

Table 16: Linguistic Terms and Fuzzy Numbers

Linguistic Terms for Criteria and Alternatives	Triangular fuzzy number
(VH) Very High Influence	(0.75, 1,0, 1.0)
(H) High Influence	(0.50, 0.75, 1.0)
(L) Low Influence	(0.25, 0.50, 0.75)
(VL) Very Low Influence	(0.0, 0.25, 0.50)
(No) No Influence	(0.0, 0.0, 0.25)

DEMATEL Step 3: Generate the fuzzy direct relation matrix

According to the evaluation of the criteria represented by language phrases, decision-makers produced a binary comparison matrix (fuzzy direct relationship matrix). Linguistic variables express the relationship between factors. Formulas turn linguistic phrases into fuzzy triangular numbers (7).

$(\tilde{z}_{ij} = (z_{ij,l}, z_{ij,m}, z_{ij,u}))$

$$downright\tilde{z} = \begin{bmatrix} 0 & \tilde{z}_{12}\cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & \tilde{z}_{22}\cdots & \tilde{z}_{2n} \\ \vdots & \vdots \ \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2}\cdots & 0 \end{bmatrix} \text{(Eq.7)}$$

DEMATEL Step 4: Normalize the fuzzy direct relation matrix

The average of the expert-created paired comparison matrices was used to construct a single assessment matrix. Then, the direct relation matrix is normalized with formulas (8), (9), and (10)

$$downright\tilde{x} = \begin{bmatrix} x_{11} & \tilde{x}_{12}\cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22}\cdots & \tilde{x}_{2n} \\ \vdots & \vdots \ \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2}\cdots & \tilde{x}_{nn} \end{bmatrix} \qquad \text{(Eq.8)}$$

$$r_s = \max\left(\sum_{\substack{i=1 \\ 1\le i\le n}}^{n} \tilde{z}_{ij,s}\right) \qquad \text{(Eq.9)}$$

$\forall$s=1,m,u

$$\tilde{x}_{ij} = \left(\frac{z_{ij,1}}{r_1}, \frac{z_{ij,m}}{r_m}, \frac{z_{ij,u}}{r_u}\right) \qquad \text{(Eq.10)}$$

Using the formula (2) to reduce data to a single matrix, all columns are summed and the biggest value for each column is defined as "r." After dividing the matrix by "r," a normalized direct relationship matrix is created.

DEMATEL Step 5: Calculate the fuzzy total-relation matrix

Fuzzy Total Direct Relationship Matrix formulas in (11).

$$\begin{aligned} \left[l_{ij}^{n}\right] &= x_l \times (I - x_l)^{-1} \\ \left[m_{ij}^{n}\right] &= x_m \times (I - x_m)^{-1} \qquad \text{(Eq.11)} \\ \left[u_{ij}^{n}\right] &= x_u \times (I - x_u)^{-1} \end{aligned}$$

$$downright\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12}\cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22}\cdots & \tilde{t}_{2n} \\ \vdots & \vdots \ \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2}\cdots & \tilde{t}_{nn} \end{bmatrix}$$

DEMATEL Step 6: Defuzzify Total Relation Matrix

After creating the Fuzzy Sum Relationship matrix, the formula (12) and (13) were used to transform fuzzy numbers to accurate numbers. $\widetilde{\mathrm{D}}_i$ and $\widetilde{\mathrm{R}}_i$ are fuzzy numbers. Clarification uses formulas to transform triangular numbers into a single value (14).

The sum of columns $\widetilde{\mathrm{R}}_i$ and rows $\widetilde{\mathrm{D}}_i$ are determined after finding the Fuzzy Sum relation matrix.

$$\widetilde{\mathrm{D}}_i = \sum_{j=1}^{n} \tilde{t}_{ij} \qquad \text{(i=1,2,…,n)} \qquad \text{(Eq.12)}$$

$$\widetilde{\mathrm{R}}_i = \sum_{i=1}^{n} \tilde{t}_{ij} \qquad \text{(j=1,2,…,n)} \qquad \text{(Eq.13)}$$

DEMATEL Step 7: Determination of Affected and Affecting Criteria

(D i+R i) and (D i-R i) were used to determine one criterion's influence on the other. If (D i-R i) is negative on the vertical axis, the factor is impacted, while a positive value implies it's in the effecting group.

DEMATEL Step 8: Calculation of Weights

All criteria are weighted by formula (14). With (15), factor weights are normalized.

$$W_i = \left\{\sqrt{(D_i + R_i)^2 + (D_i - R_i)^2}\right\} \qquad \text{(Eq.14)}$$

$$W_i = \frac{w_i}{max_{1\le i\le n}(w_i)} \forall i = 1,2,\ldots,n \qquad \text{(Eq.15)}$$

The study presents an integrated methodology employing fuzzy DEMATEL and fuzzy TOPSIS. The approach aims to discover a solution by utilizing fuzzy TOPSIS to rank alternatives after defining initial criteria weights with fuzzy DEMATEL.

ANNEX 2: Chen's Fuzzy TOPSIS method Implementation Steps

Below are the application steps of Chen's (2000) fuzzy TOPSIS Method used in this study.

TOPSIS Step 1: Determination of Decision Makers and Solution Alternatives

In the study, alternatives are chosen for expert review.

TOPSIS Step 2: Evaluation of criteria and alternatives with linguistic variables

The fuzzy scale, which correlates to the linguistic variables used to evaluate the criteria, was utilized to get the experts' opinion on the alternatives. After selecting linguistic variables for criterion weights, alternatives are assessed using the same variables.

TOPSIS Step 3: Converting Evaluations to Fuzzy Numbers

Verbal variables and Fuzzy DEMATEL implementation steps are turned into fuzzy triangular numbers to assess decision makers' relevance weights and alternatives. At this step, criterion weights are defined.

TOPSIS Step 4: Set Fuzzy Decision Matrix

Fuzzy TOPSIS is a multi-criteria decision-making issue described by decision-makers, decision criteria, and options as in formula (16). In this stage, the fuzzy decision matrix is created by averaging the expert group's fuzzy numbers.

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \mathrm{W}=[\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n] \quad \text{(Eq.16)}$$

TOPSIS Step 5: Determine the Normalized Decision Matrix

By using equations (17), (18), the fuzzy decision matrix is normalized.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \mathrm{j} \in B, c_j^* = \max_i c_{ij} \qquad \text{(Eq.17)}$$

$$\tilde{r}_{ij} = \left(\frac{a_{\bar{j}}}{c_{ij}}, \frac{a_{\bar{j}}}{b_{ij}}, \frac{a_{\bar{j}}}{a_{ij}}\right), \mathrm{j} \in C, a_{\bar{j}} = \min_i a_{ij} \qquad \text{(Eq.18)}$$

TOPSIS Step 6: Determine a weighted normalized decision matrix

With formula (19), each fuzzy number in the normalized decision matrix is multiplied by the fuzzy DEMATEL method's criteria weight.

$$\tilde{V} = [\tilde{v}_{ij}] = \tilde{r}_{ij}(.)\widetilde{w}_j \quad \mathrm{i}=1,2,\dots,\mathrm{m}, \quad \mathrm{j}=1,2,\dots,\mathrm{n} \quad \text{(Eq.19)}$$

TOPSIS Step 7: Determine a Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)

A* while defining the fuzzy positive ideal solution, A^- is defined as the fuzzy negative ideal solution.

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \qquad \text{(Eq.20)}$$

$$A^- = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \quad \mathrm{j}=1,\dots,\mathrm{n} \qquad \text{(Eq.21)}$$

Here it is accepted as $\tilde{v}_j^* = (1,1,1) ve \tilde{v}_j^- = (0,0,0)$. There is (0, 0, 0) value as much as the number of decision criteria in $AA*$ and as much as the number of decision criteria in $(1,1,1), A^-$.

TOPSIS Step 8: Calculation of the seperation matrix

Distances between fuzzy positive and negative ideal solutions are determined using the formula (22) and (23).

$$S_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*) \; i=1,2,\dots,m \qquad \text{(Eq.22)}$$

$$S_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \; i=1,2,\dots,m \qquad \text{(Eq.23)}$$

Here, d is the Vertex distance between fuzzy numbers. This technique calculates (24) the distance between two fuzzy triangular integers, $\widetilde{m}(m_1, m_2, m_3)$ and $\tilde{n}(n_1, n_2, n_3)$.

$$\mathrm{d}(\widetilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \quad \text{(Eq.24)}$$

TOPSIS Step 9: Calculation Closeness Coefficients for Each Alternative

Closeness Coefficients are determined using equations (25) and (26):

$$\mathrm{cl}_i^* = \frac{d_i^*}{d_i^* + d_i^-}, i = 1,2,\dots,m \quad \text{(Eq.25)}$$

$$\mathrm{cl}_i^- = \frac{d_i^-}{d_i^* + d_i^-}, i = 1,2,\dots,m \quad \text{(Eq.26)}$$

TOPSIS Step 10: Preference order ranking High proximity coefficient suggests an option is closer to a PIS. All alternatives are offered and the one with the highest closeness coefficient is chosen.