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Efficiency analysis technique with input and output satisficing approach based on Type-2 Neutrosophic Fuzzy Sets: A case study of container shipping companies

Sarfaraz Hashemkhani Zolfani[a,1], Ömer Faruk Görçün[b,2], Mustafa Çanakçıoğlu[c,3], Erfan Babaee Tirkolaee[d,*,4]

[a] School of Engineering, Universidad Catolica del Norte, Larrondo 1281, Coquimbo, Chile
[b] Department of Business Administration, Faculty of Economics, Administrative and Social Sciences, Kadir Has University, İstanbul, Turkey
[c] Istanbul Gelisim University, Faculty of Applied Sciences, Department of E-Trade and Management, Cihangir Avenue, Şehit Jandarma Komando Er Hakan Öner St. No:1 Avcılar, Istanbul, Turkey
[d] Department of Industrial Engineering, Istinye University, Istanbul, Turkey

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ABSTRACT

This work tries to discuss and evaluate the advantages and superiorities of the extended Efficiency Analysis Technique with Input and Output Satisficing (EATWIOS) method based on Type-2 Neutrosophic Fuzzy Numbers (T2NFNs). The suggested model is maximally stable and robust by considering sensitivity analysis results which demonstrates a new performance analysis approach based on T2NFN sets. The proposed model deals with the input and output criteria and considers existing uncertainties arising from insufficient information and the dynamic structure of the industries. The model's basic algorithm has a unique structure compared to the previous performance analysis technique, and it does not require applying additional weighting techniques to identify the criteria weights. To the best of our knowledge, the extended version of the EATWIOS technique based on the T2NFN set is presented for the first time. The developed model provides reasonable and logical results to practitioners because it deals with satisfactory outputs instead of optimal outputs. This model is an immensely strengthened version of the EATWIOS technique, as the T2NFN sets treat predictable and unpredictable uncertainties. The suggested T2NFN-EATWIOS is then applied to a real-world assessment problem in the container shipping industry. The obtained results are pretty reasonable and logical. Moreover, the results of a comprehensive sensitivity analysis with three stages approve the robustness of the suggested model.

1. Introduction

Decision-making environments are vulnerable to uncertainties existing in evaluation processes. When a decision-maker must produce a reliable solution concerning a highly complicated multi-attribute decision problem, the practitioner needs extensive information and data to handle this evaluation problem. As a classical approach, decision-makers try to collect the right and updated information and data from official databases. Moreover, the relative significance of the information and data is increased when decision-makers make a performance analysis since the performance, or efficiency analysis requires updated and actual data. However, collecting reliable and correct data may not always be possible, and practitioners may have to decide with imperfect information and insufficient data. In this circumstance, the significance of the implemented decision-making tool is increased because it is essential to apply an efficient and practical mathematical model that can handle many complicated uncertainties to reach more reliable, acceptable, and rational results. In addition, in many industries and fields,

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* Corresponding author.
E-mail addresses: sarfaraz.hashemkhani@ucn.cl (S.H. Zolfani), omer.gorcun@khas.edu.tr (Ö. Faruk Görçün), mcanakcioglu@gelisim.edu.tr (M. Çanakçıoğlu), erfan.babaee@istinye.edu.tr (E.B. Tirkolaee).

[1] ORCID: https://orcid.org/0000-0002-2602-3986.
[2] ORCID: https://orcid.org/0000-0003-3850-6755.
[3] ORCID: https://orcid.org/0000-0002-1536-7097.
[4] ORCID: https://orcid.org/0000-0003-1664-9210.

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encountered uncertainties may be more complicated because it consists of unpredictable ambiguities arising from the industry's highly dynamic structure, and these uncertainties make it difficult to produce a reasonable solution. Hence, a mathematical tool that can capture and process these ambiguities is required to produce reasonable and logical results.

1.1. Motivations

As a consequence of an extensive literature review, we could find only 31 studies dealing with the performance of maritime shipping companies directly or indirectly. When these studies were examined in detail, we noted that most of them focused on the financial efficiency of shipping companies. Most of the remaining studies dealt with the operational or environmental performance of maritime shipping firms. However, in the relevant literature, there is no study evaluating the financial and operational performance of shipping companies together by associating them. Hence, the former studies could not present a robust and practical framework that can deal with uncertainties to evaluate both performance sets. As a critical research gap, almost all studies in the literature did not consider the relationship and interactions between financial and operational performance.

In addition, most of the studies dealing with the financial efficiency of maritime shipping companies used Data Envelopment Analysis (DEA) model to examine the financial performance of shipping firms. However, the DEA cannot be used as a methodological frame for analyzing shipping firms' performances due to its critical drawbacks and structural problems. First, it is susceptible to the determination of the criteria; when the criteria are changed, acquired overall results may change dramatically, so added or eliminated criteria may cause severe changes in the overall results. It confirms that the DEA technique suffers from the rank reversal problem. As a result, it may not be a sufficiently trustworthy methodological frame for practitioners in the maritime industry grappling with severe volatilities and tremendously complicated uncertainties. Also, the DEA technique is only used to evaluate the efficiency and can evaluate an alternative as efficient or inefficient. Hence, the approach's ability to compare the alternatives is not satisfactory. Besides, it has a complicated procedure, and implementation of the DEA is laborious and complicated for decision-makers (Färe et al., 2015; Alirezaee & Afsharian, 2007; Johns et al., 1997).

Apart from the DEA technique, various decision-making tools were used to analyze the shipping companies' financial performance and efficiency in the literature. While the Grey Relational Analysis (GRA) approach was employed by Wang (2009) to analyze the financial efficiency of Taiwan container shipping companies, Wang and Lee (2009) applied the TOPSIS technique for a similar study. To evaluate maritime shipping firms' financial efficiency, the researchers also used various ranking approaches, such as Analytic Hierarchy Process (AHP), Elimination and Choice Translating Reality (ELECTRE), and the Weighted Product Model (WPM). However, these approaches are the ranking methods and do not present comprehensive and detailed information about the financial performance of the companies except for the ranking of the alternatives. In addition, notably AHP and TOPSIS, most of the applied frameworks to analyze the financial efficiency of shipping firms suffer from the rank reversal problem and cannot make a sufficiently trustworthy decision-making environment to the practitioners who are in the maritime industry. Furthermore, the previous research works have not provided any satisfactory and sufficient implication, evaluation, and discussion on ranking results acquired in the earlier studies. Addedly, most of the author(s) preferred to use classical objective and subjective decision-making methods and made performance or efficiency analyzes based on crisp and definite numerical values. Therefore, most studies assessing maritime shipping companies' efficiencies have not considered highly significant and complicated uncertainties. Few authors preferred to use classical fuzzy sets (Zadeh, 1965) to assess the financial performance of shipping companies. However, the fuzzy set theory cannot capture and process ambiguities in the maritime industry having excessively complicated uncertainties, as it considers membership function only and overlooks unpredictable ambiguities, such as inconsistency, vagueness, and imprecision.

Being not adequately investigated the determinants for shipping firms' operational and financial performances is another research gap. In general, it is not clear how the criteria and factors were determined in most studies. Also, the studies focusing on financial efficiency used a range of financial variables and data derived from financial statements and balance sheets. Besides, it is also unclear why some companies were included in the scope of the assessment or left out of the assessment. While Wang (2008, 2009), Wang and Lee (2009), and Lu et al. (2009) evaluated Taiwan's container shipping companies' financial performance, Lee and Lin (2013) and Lee et al. (2012, 2018) comparatively examined assessed the financial efficiencies of Taiwan's and South Korea' liner shipping firms. However, these studies' acquired outcomes and findings cannot be generalized for the whole of the container shipping industry, an international and global sector, as these studies only focused on a country's maritime shipping companies.

Furthermore, as the previous studies focusing on shipping companies' financial efficiency could only make evaluations based on financial data collected from international stock exchanges, it cannot include the companies which are not operand in stock exchanges even though their capacities and scales are tremendously large, in the scope of the evaluation. It may cause to raising doubts concerning the acquired outcomes' reliability, rationality, and suitability for real-life conditions. Similarly, these studies are entirely dependent on the data declaration of maritime shipping companies which are operand in the stock exchanges concerning their financial positions and operations. Moreover, these data must be correct, accurate and trustworthy to acquire reasonable and logical results at the end of the financial analyzes. Most of the studies used short-term financial data and information about the companies, and these short-term data may not be sufficient to obtain comprehensive outcomes and findings which can be generalized to all maritime shipping companies. Even if the container shipping companies are operands in the stock market, their structure and features can change due to mergers, alliances, and partnerships among the companies; monitoring these companies' financial positions can be pretty difficult, particularly for mid and long terms. For example, a large-scale container shipping firm that is an operand in the stock exchange for ten years and declared financial data and information about its financial position may merge with different container firm(s), while the first company may disappear abruptly, financial position and data of the second shipping company can change that cannot be comparable with the financial data of the company for the previous year. From this perspective, we noticed that the prior studies still have not found logical and reasonable solutions to overcome these complexities and ambiguities. As a critical and significant gap in the literature, the earlier studies made financial analyzes based on tremendously volatile short-term financial data collected from stock exchanges' databases (i.e., mostly Thomson Reuters and Bloomberg). Hence, the acquired results are untrustworthy and cannot be generalized. In addition, not considering the judgments, experiences, and knowledge of the decision-makers, which are precious in evaluation processes, is the next research gap noted in the current paper. However, professionals' experiences and knowledge play critical and vital roles in the maritime industry, having highly complicated uncertainties and severe fluctuations.

1.2. Manuscript structure

The remaining sections are structured as follows. Section 2 describes the background of the study in detail. In Section 3, the suggested model and its implementation steps are described. In Section 4, T2NFN-EATWIOS, the recommended model is applied to analyze the financial and operational efficiencies of the CSCs. Moreover, in the last phase of Section 4, an extensive sensitivity analysis with three stages is performed to test the model's validity, stability, and robustness. In Section 5, the obtained results are represented. Section 6 finalizes the study with a discussion of the practical implications, and eventually, the challenges and suggestions for future work are pointed out in this last section.

2. Background

The EATWIOS approach developed by Peters and Zelewski (2006) is an entirely consistent, robust, and practical performance analysis technique. Thus, it is a very popular decision-making tool in comparison with the other efficiency analysis approaches, and the number of studies using this approach in the literature is increasing (Altıntaş, 2022; Arslan et al., 2019; Aytekin, 2020, 2021; Aytekin et al., 2022; Bansal et al., 2014; Çanakçıoğlu, 2019; Görçün,2019a, 2019b, 2019c; Ilıkkan et al., 2021; Özbek, 2015a; Ozbek, 2015; Özbek, 2015b; Özdağoğlu, 2019; Soni et al., 2016; Yüksekyıldız, 2022). These papers used crisp values obtained from statistical databases or actual data collected by performing fieldwork. However, it may not be possible to obtain crisp values and actual data in real life; and decision-makers may evaluate with imperfect information and a lack of data.

The maritime industry is vague and volatile by its nature (Notteboom & Siu Lee Lam, 2014). Aside from external factors, such as wars, terror, and global financial crises, shipping industry uncertainties arise from the industry's dynamic and volatile structure (Lam et al., 2021). As the entry into force of these regulations is a lengthy process requiring the member states' ratification (Haehl & Spinler, 2018), regulations made by the International Maritime Organization (IMO), such as sustainability, protection of the environment, financial and economic regulations for the industry, and protection of competition, cause severe uncertainties in the maritime industry. Hence, these uncertainties substantially influence the industry's strategic decisions and make it challenging to take investment decisions for maritime shipping companies. In addition, the most significant reason for the uncertainty is volatility and variability in demand for maritime shipping services. It also causes volatility and vagueness in freight charges, shipping costs, and the overall performance of the maritime shipping industry. Another factor causing uncertainty in the maritime industry is the extraordinary fluctuations in bunker prices (i.e., fuel prices) (Albertijn et al., 2011; Kuo et al., 2017). Volatile bunker prices influence maritime shipping companies' costs, profits, and overall performance, making it difficult to manage them. Apart from economic and financial uncertainties, making strategic decisions in the maritime industry becomes difficult due to operational uncertainties, as they tangle the decision-making processes. Notably, uncertain waiting times in ports, being excessively dependent on climate conditions, and ship travel times, which are pretty variable, increase the uncertainties and their complexity degrees in the maritime shipping industry (Jia et al., 2020).

Container shipping is one of the most affected industries by uncertainties because it has to produce regular shipping services with multiple networks, lines, and routes. Those can be accepted as the container shipping industry's idiosyncrasy as they differ from other shipping types, such as tanker, bulk carrier, and Ro-Ro shipping. These unique features increase risks in the container shipping industry in an uncertain environment and make designing and conducting container shipping operations challenging for liner shipping companies (Mohd Salleh et al., 2015). In addition, uncertainties based on the industry's characteristics can affect the liner shipping firms' investment and other managerial and strategic decisions. Aside from these ambiguities, conditions and situations can change quickly and abruptly in the liner shipping industry. For instance, business combinations, mergers, strategic or tactical alliances and partnerships are common in the current industry (Lam et al., 2021). Thus, acquiring real-time information and data to evaluate the container shipping companies' financial and operational performance is excessively difficult. Although some financial data of companies which operand on the stock exchange can be collected from various databases, such as Thomson Reuters, collecting information and data concerning the shipping operations of the liner companies is pretty difficult. The main reason is that information and data transparency in the container shipping industry is severely low (Nguyen et al., 2019; Panayides et al., 2011). Consequently, notably in the container shipping sector, the maritime industry tries to overcome these excessively complicated uncertainties to solve highly complicated decision-making problems faced in shipping (Lam et al., 2021).

Thus, many complicated uncertainties affect the evaluation processes, and these uncertainties must be considered to obtain reasonable and logical results when performing a performance analysis in various industries including the maritime shipping industry. In the relevant literature, we could only find one paper proposing a fuzzy performance analysis tool based on classical fuzzy sets by considering uncertainties (Görçün et al., 2022). This research is the first and most successful example presenting the extended version of the EATWIOS method, and it provided satisfactory and reasonable results to make performance analysis for the global retail chains. However, the suggested fuzzy approach in this study may not produce a satisfactory solution concerning overcoming extraordinarily complex and unpredictable ambiguities, such as inconsistency, vagueness and imprecision encountered in the maritime industry (Cho, 2014; Good, 2018; Salokannel et al., 2018; Wang & Vogt, 2019) due to the classical fuzzy sets' disadvantages and structural problems.

2.1. Contributions

Considering the above-mentioned research gaps, the current study introduces an extension of the EATWIOS approach with the help of the Type-2 Neutrosophic Fuzzy Numbers (T2NFNs) as a robust, effective, and reliable performance analysis model that can handle extraordinarily complex uncertainties. The model associates the advantages of the EATWIOS and T2NFNs. The proposed model' theoretical contributions are summarised as follows:

i. The EATWIOS approach can show whether the obtained outputs are satisfactory for decision-makers (Kundakcı, 2019). Hence, it considers satisfactory outputs instead of optimal outputs, which cannot be reached, making it a more realistic approach (Bansal et al., 2014). Besides, the technique has a basic practical algorithm and can easily be implemented by decision-makers without requiring advanced mathematical knowledge (Görçün, 2019a, 2020; Görçün et al., 2022). Also, it can provide logical results with fewer calculations. The EATWIOS has relatively few implementation steps compared to the existing efficiency analysis approaches.

ii. The T2NFN sets provide more effective, practical, and powerful approaches to capturing and processing unpredictable uncertainties, aside from predictable ambiguities, than classical fuzzy sets. Some limitations affecting the Type-1 fuzzy sets (T1Fs) are out of the question for the Type-2 fuzzy sets (T2Fs), and T2Fs have many more valuable advantages over T1Fs (Karaşan & Kahraman, 2018). T1Fs consider membership functions for the elements, and an element can be a member of a set only, or it is not a member of the set (Mapari & Naidu, 2016). Thus, T1Fs cannot provide satisfactory results concerning capturing and processing all uncertainties such as inconsistency, inexactness, and impreciseness (Deveci et al., 2022; Radwan et al., 2016). T2Fs are highly effective in overcoming these uncertainties.

iii. Neutrosophic numbers (NNs) have significant advantages in capturing and processing imprecise, incomplete, vague and inconsistent information (Das et al., 2020). Besides, the NNs consider both predictable and unpredictable uncertainties (Nagarajan et al., 2019). Also, it does not require an additional weighting technique to calculate the criteria weights, as it can

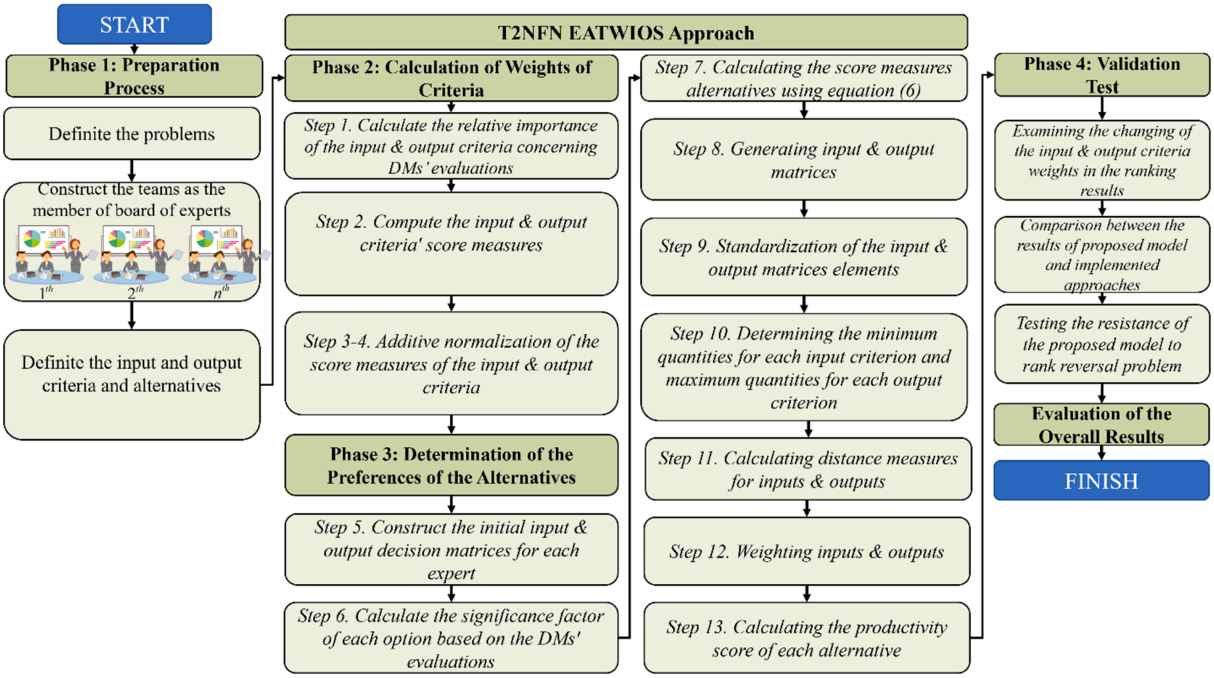


Fig. 1. Proposed T2NFN-EATWIOS model and its implementation steps.

compute those by implementing the basic algorithm of the developed model.

In addition to conceptual contributions, the current research has several beneficial executive implications for the maritime industry and other fields, such as various branches of engineering, management, and transportation. These executive implications are highlighted as follows:

I. Our findings may be a roadmap for self-evaluating Container Shipping Companies' (CSCs) financial, operational, and overall performances. Practitioners in the current industry can analyze their performance by comparing it with their competitors and strategic partners. Thus, it may be possible that the maritime industry and the global container shipping system can have a more resilient and robust structure. Also, the obtained findings and the proposed decision-making frame can guide them in identifying strategies to improve their operations.
II. Stockholders and investors can assess CSCs concerning making investments using the proposed model and make more rational and reasonable decisions. Furthermore, this approach can provide an opportunity to be more reputable in the stock market for the CSCs.
III. The Global Supply Chains (GSCs) can identify the options that are optimal, reasonable, and logical by assessing the financial and operational performances of the CSCs with the aid of the proposed performance analysis approach in our research. Hence, they can make a more rational and optimal selection. Depending on that, the GSCs can be re-structured as more resilient and robust.

Consequently, the contributions of the manuscript can be summarized as follows. When the earlier studies are evaluated, there are two main trends dealing with performance analysis of the maritime shipping companies in the relevant literature. The first is to evaluate the financial performance and efficiency of the maritime shipping companies which are operand in the international stock exchanges using their historical financial data collected from stock exchanges' databases. Hence, while the authors preferred efficiency analysis techniques, such as DEA, analyzes were generally performed using crisp and definite financial data. Though these studies are relatively scarce compared to the studies dealing with the financial performance of maritime shipping firms, these studies represent the second crucial trend in the relevant literature. However, according to the authors' information, there is no study examining maritime shipping companies' financial and operational performances with a holistic approach in the literature.

By considering these research gaps, the current study presents a holistic approach to analyze the overall performance of container shipping companies by merging financial and operational performance analyzes for the first time in the literature. Another contribution of the study is to take benefit from Type-2 Neutrosophic fuzzy sets to capture and process the highly complicated predictable and unpredictable uncertainties, existing in the maritime industry by the industry's nature. Furthermore, it has strengthened the EATWIOS technique that is a very practical and robust performance analysis tool, as the EATWIOS approach can successfully overcome extraordinary ambiguities existing in the maritime shipping industry by extending with the help of T2NFN sets. Consequently, this work is the first study presenting a robust and practical mathematical tool that can handle excessively complicated uncertainties to carry out performance analyzes for various industries aside from the maritime shipping industry.

In addition, the researchers preferred to construct a board of experts involving professionals to benefit from experts' experiences and knowledge in the earlier studies in the literature related to decision-making problems faced in various fields. However, decision-making processes may also require evaluations of specialists in different fields. For instance, a decision-maker who is an expert in maritime shipping management may not have sufficient technical information on the financial management of shipping companies. By noticing this research gap, this study designed each board of experts' membership as a sub-working group instead of identifying a professional for each membership. The researchers formed each sub-working group involving one senior executive, a finance and accounting department manager, and an operation manager. This approach, as another precious contribution of the current study, eliminates or minimizes misevaluation and mistake risks due to imperfect and insufficient information of experts, as each sub-working group makes evaluations by carrying out negotiation processes.

3. Proposed methodology

This section demonstrates the proposed T2NFN-EATWIOS model where its implementation steps are demonstrated in Fig. 1. Accordingly, there are four main phases in order to apply the model and evaluate the final results. It should be noted that the significance levels or weights of different criteria as well as the ordering of specific criteria are denoted with the help of linguistic terms, which is based on the T2NN linguistic scale represented in Table 3.

3.1. Preliminaries on the neutrosophic sets

This section reviews certain concepts about Type-2 Neutrosophic Numbers (T2NNs) to build up a base for the integrated technique. The preliminary information about T2NNs is given in Appendix A.

3.2. Computing the criteria weights

Here, the weights coefficients of the criteria are computed by following the basic algorithm of the suggested model. For this purpose, the implementation steps given below are followed.

***Step* 1.** Compute the relative importance of the input and output factors concerning experts' assessments: In this step, e number of teams $\xi = \{\xi_1, \xi_2, \ldots, \xi_e\}$(i.e., each team consists of three experts) evaluate the input $I= \{I_1, I_2, \ldots, I_n\}$ and output $O =\{o_1, o_2, \ldots, o_n\}$ criteria using the T2NN linguistic scale. Thus, T2NFN matrices consisting of expert assessments are formed.

In this phase, the weight coefficients of the criteria are computed. Here,

$\Im^i = \left[\gamma_{jb}\right]^i_{n\times e}$, ($j = 1,..,n$; $b = 1,2,\ldots,e$) and$\Im^o = \left[\gamma_{jb}\right]^o_{n\times e}$, ($j = 1,..,n$; $b = 1,2,\ldots,e$) are the initial matrices for the input and output factors, respectively; where γ^i_{jb} represents the elements of the input matrix;$\gamma^i_{jb} = \left[\left(\gamma^{T_T}_{jb}, \gamma^{T_I}_{jb}, \gamma^{T_F}_{jb}\right)^i, \left(\gamma^{I_T}_{jb}, \gamma^{I_I}_{jb}, \gamma^{I_F}_{jb}\right)^i, \left(\gamma^{F_T}_{jb}, \gamma^{F_I}_{jb}, \gamma^{F_F}_{jb}\right)^i\right]$;$\gamma^o_{jb}$ represents the elements of the output matrix;$\gamma^o_{jb} = \left[\left(\gamma^{T_T}_{jb}, \gamma^{T_I}_{jb}, \gamma^{T_F}_{jb}\right)^o, \left(\gamma^{I_T}_{jb}, \gamma^{I_I}_{jb}, \gamma^{I_F}_{jb}\right)^o, \left(\gamma^{F_T}_{jb}, \gamma^{F_I}_{jb}, \gamma^{F_F}_{jb}\right)^o\right]$.

***Step* 2.** Compute the input and output criteria' score measures: Afterwards, the significance factor of each criterion is determined by considering the experts' evaluations. It is determined for each degree of the T2NFN; thus, a T2NFN is generated for each criterion. It is calculated by applying Eqs. (8) and (9):

$$SF^i_j = \begin{bmatrix} \left(\frac{\sum_{k=1}^e \gamma^{T_T}_{kj} - \prod_{k=1}^e \gamma^{T_T}_{kj}}{e}, \frac{\sum_{k=1}^e \gamma^{T_I}_{kj} - \prod_{k=1}^e \gamma^{T_I}_{kj}}{e}, \frac{\sum_{k=1}^e \gamma^{T_F}_{kj} - \prod_{k=1}^e \gamma^{T_F}_{kj}}{e}\right)^i, \\ \left(\frac{\prod_{k=1}^e \gamma^{I_T}_{kj}}{e}, \frac{\prod_{k=1}^e \gamma^{I_I}_{kj}}{e}, \frac{\prod_{k=1}^e \gamma^{I_F}_{kj}}{e}\right)^i, \\ \left(\frac{\prod_{k=1}^e \gamma^{F_T}_{kj}}{e}, \frac{\prod_{k=1}^e \gamma^{F_I}_{kj}}{e}, \frac{\prod_{k=1}^e \gamma^{F_F}_{kj}}{e}\right)^i \end{bmatrix}, \tag{8}$$

$$SF^o_j = \begin{bmatrix} \left(\frac{\sum_{k=1}^e \gamma^{T_T}_{kj} - \prod_{k=1}^e \gamma^{T_T}_{kj}}{e}, \frac{\sum_{k=1}^e \gamma^{T_I}_{kj} - \prod_{k=1}^e \gamma^{T_I}_{kj}}{e}, \frac{\sum_{k=1}^e \gamma^{T_F}_{kj} - \prod_{k=1}^e \gamma^{T_F}_{kj}}{e}\right)^o, \\ \left(\frac{\prod_{k=1}^e \gamma^{I_T}_{kj}}{e}, \frac{\prod_{k=1}^e \gamma^{I_I}_{kj}}{e}, \frac{\prod_{k=1}^e \gamma^{I_F}_{kj}}{e}\right)^o, \\ \left(\frac{\prod_{k=1}^e \gamma^{F_T}_{kj}}{e}, \frac{\prod_{k=1}^e \gamma^{F_I}_{kj}}{e}, \frac{\prod_{k=1}^e \gamma^{F_F}_{kj}}{e}\right)^o \end{bmatrix}. \tag{9}$$

Here, e is the number of experts and $\gamma^i_j = \left[\left(\gamma^{T_T}_j, \gamma^{T_I}_j, \gamma^{T_F}_j\right)^i, \left(\gamma^{I_T}_j, \gamma^{I_I}_j, \gamma^{I_F}_j\right)^i, \left(\gamma^{F_T}_j, \gamma^{F_I}_j, \gamma^{F_F}_j\right)^i\right]$ symbolizes the value attributed by the decision-makers to input criterion j^i and $\gamma^o_j = \left[\left(\gamma^{T_T}_j, \gamma^{T_I}_j, \gamma^{T_F}_j\right)^o, \left(\gamma^{I_T}_j, \gamma^{I_I}_j, \gamma^{I_F}_j\right)^o, \left(\gamma^{F_T}_j, \gamma^{F_I}_j, \gamma^{F_F}_j\right)^o\right]$ output criterion j^o.

***Steps* 3–4.** Additive normalization of the input and output criteria scores measures: The score measures are computed using Eq. (2). Thus, a vector of order 1 × n is further normalized using Eq. (10) to identify the input (w^i_j) and output factors (w^o_j) weights:

$$w^i_j = \frac{S\left(SF^i_j\right)}{\sum_{j=1}^n S\left(SF^i_j\right)};\ w^o_j = \frac{S\left(SF^o_j\right)}{\sum_{j=1}^n S\left(SF^o_j\right)} \quad (j = 1, 2, 3, \ldots, n), \tag{10}$$

where $S\left(SF^i_j\right)$ and $S\left(SF^o_j\right)$ represent the score measure given in Eq. (6), n is the criteria number. Thus, we acquire the input and output factors weight coefficients vector $w_j = (w_1, w_2, \ldots, w_n)^T$ employed in the next step to compute the weighted sequence of alternatives.

3.3. Calculation of the performance values of alternatives

***Step* 5.** Generate the initial decision matrices ($\aleph^b$): In this stage, experts make linguistic assessments by taking into account the linguistic scale for the alternatives. Next, these assessments are converted to the T2NNs matching with the scale. Afterwards, each expert is denoted through the basic decision matrices for inputs$I^b = \left[\overline{I}^b_{ij}\right]_{m\times n}$, where$I^b_{ij} = \left[\left(I^{T_T(b)}_{ij}, I^{T_I(b)}_{ij}, I^{T_F(b)}_{ij}\right), \left(I^{I_T(b)}_{ij}, I^{I_I(b)}_{ij}, I^{I_F(b)}_{ij}\right), \left(I^{F_T(b)}_{ij}, I^{F_I(b)}_{ij}, I^{F_F(b)}_{ij}\right)\right]$,$1\leqslant b\leqslant e$; $i = 1,2,\ldots,m$; $j = 1,2,\ldots n$. Each pair I^b_{ij} takes a value from the predefined T2NN scale for input factors. Moreover, for outputs$o^b = \left[\overline{o}^b_{ij}\right]_{m\times n}$, where$\overline{o}^b_{ij} = \left[\left(\overline{o}^{T_T(b)}_{ij}, \overline{o}^{T_I(b)}_{ij}, \overline{o}^{T_F(b)}_{ij}\right), \left(\overline{o}^{I_T(b)}_{ij}, \overline{o}^{I_I(b)}_{ij}, \overline{o}^{I_F(b)}_{ij}\right), \left(\overline{o}^{F_T(b)}_{ij}, \overline{o}^{F_I(b)}_{ij}, \overline{o}^{F_F(b)}_{ij}\right)\right]$,$1\leqslant b\leqslant e$; $i = 1,\ldots,m$; $j = 1,\ldots n$. Each pair $\overline{o}^b_{ij}$ takes a value from the predefined T2NN scale for output factors.

***Step* 6.** Determine the significance factor of each alternative by considering experts' assessments: Then, the alternatives' relative significances are determined with respect to members' assessments concerning input factors. In this respect, Eq. (11) is implemented:

$$I^{SF}_{ij} = \begin{bmatrix} \left(\frac{\sum_{k=1}^e \overline{\theta}^{T_T}_{kij} - \prod_{k=1}^e \overline{\theta}^{T_T}_{kij}}{e}, \frac{\sum_{k=1}^e \overline{\theta}^{T_I}_{kij} - \prod_{k=1}^e \overline{\theta}^{T_I}_{kij}}{e}, \frac{\sum_{k=1}^e \overline{\theta}^{T_F}_{kij} - \prod_{k=1}^e \overline{\theta}^{T_F}_{kij}}{e}\right), \\ \left(\frac{\prod_{k=1}^e \overline{\theta}^{I_T}_{kij}}{e}, \frac{\prod_{k=1}^e \overline{\theta}^{I_I}_{kij}}{e}, \frac{\prod_{k=1}^e \overline{\theta}^{I_F}_{kij}}{e}\right), \\ \left(\frac{\prod_{k=1}^e \overline{\theta}^{F_T}_{kij}}{e}, \frac{\prod_{k=1}^e \overline{\theta}^{F_I}_{kij}}{e}, \frac{\prod_{k=1}^e \overline{\theta}^{F_F}_{kij}}{e}\right) \end{bmatrix}^i, \tag{11}$$

where e shows the number of experts. Thus, the T2NN matrix of options in regard to input factors is formed with the help of Eq. (12):

$$\aleph = \begin{bmatrix} I^{SF}_{11} & I^{SF}_{12} & I^{SF}_{13} & \cdots & I^{SF}_{1n} \\ I^{SF}_{21} & I^{SF}_{22} & I^{SF}_{23} & \cdots & I^{SF}_{2n} \\ I^{SF}_{31} & I^{SF}_{32} & I^{SF}_{33} & \cdots & I^{SF}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ I^{SF}_{m1} & I^{SF}_{m2} & I^{SF}_{m3} & \cdots & I^{SF}_{mn} \end{bmatrix}, \tag{12}$$

where$I^{SF}_{ij} = \left[\left(\theta^{T_T}_{ij}, \theta^{T_I}_{ij}, \theta^{T_F}_{ij}\right), \left(\theta^{I_T}_{ij}, \theta^{I_I}_{ij}, \theta^{I_F}_{ij}\right), \left(\theta^{F_T}_{ij}, \theta^{F_I}_{ij}, \theta^{F_F}_{ij}\right)\right]^i$; $i = 1,2,\ldots,m$; $j = 1,2,\ldots,n$.

Next, similar computations are performed for output factors using Eq. (13):

$$o_{ij}^{SF}=\begin{bmatrix}\left(\frac{\sum_{k=1}^{e}\overline{\theta}_{kij}^{T_T}-\prod_{k=1}^{e}\overline{\theta}_{kij}^{T_T}}{e},\frac{\sum_{k=1}^{e}\overline{\theta}_{kij}^{T_I}-\prod_{k=1}^{e}\overline{\theta}_{kij}^{T_I}}{e},\frac{\sum_{k=1}^{e}\overline{\theta}_{kij}^{T_F}-\prod_{k=1}^{e}\overline{\theta}_{kij}^{T_F}}{e}\right),\\ \left(\frac{\prod_{k=1}^{e}\overline{\theta}_{kij}^{I_T}}{e},\frac{\prod_{k=1}^{e}\overline{\theta}_{kij}^{I_I}}{e},\frac{\prod_{k=1}^{e}\overline{\theta}_{kij}^{I_F}}{e}\right),\\ \left(\frac{\prod_{k=1}^{e}\overline{\theta}_{kij}^{F_T}}{e},\frac{\prod_{k=1}^{e}\overline{\theta}_{kij}^{F_I}}{e},\frac{\prod_{k=1}^{e}\overline{\theta}_{kij}^{F_F}}{e}\right)\end{bmatrix}^{o}, \tag{13}$$

where e represents the number of decision-makers. Consequently, the T2NN matrix of alternatives concerning output factors is constructed based on Eq. (14):

$$\Re=\begin{bmatrix} o_{11}^{SF} & o_{12}^{SF} & i_{13}^{SF} & \cdots & o_{1n}^{SF}\\ o_{21}^{SF} & o_{22}^{SF} & i_{23}^{SF} & \cdots & o_{2n}^{SF}\\ o_{31}^{SF} & o_{32}^{SF} & i_{33}^{SF} & \cdots & o_{3n}^{SF}\\ \vdots & \vdots & \vdots & \ddots & \vdots\\ o_{m1}^{SF} & o_{m2}^{SF} & o_{m3}^{SF} & \cdots & o_{mn}^{SF}\end{bmatrix}, \tag{14}$$

where$o_{ij}^{SF}=\left[\left(\theta_{ij}^{T_T},\theta_{ij}^{T_I},\theta_{ij}^{T_F}\right),\left(\theta_{ij}^{I_T},\theta_{ij}^{I_I},\theta_{ij}^{I_F}\right),\left(\theta_{ij}^{F_T},\theta_{ij}^{F_I},\theta_{ij}^{F_F}\right)\right]^{o}$; $(i=1,2,\ldots,m;$ $j=1,2,..,n)$.

***Step* 7.** Determining the score measure of options using Eq. (6): Hence, we provide the input factors' score measures matrix, which is represented by Eq. (15):

$$\overline{\aleph}=\begin{bmatrix} \aleph_{11} & \aleph_{12} & \aleph_{13} & \cdots & \aleph_{1n}\\ \aleph_{21} & \aleph_{22} & \aleph_{23} & \cdots & \aleph_{2n}\\ \aleph_{31} & \aleph_{32} & \aleph_{33} & \cdots & \aleph_{3n}\\ \vdots & \vdots & \vdots & \ddots & \vdots\\ \aleph_{m1} & \aleph_{m2} & \aleph_{m3} & \cdots & \aleph_{mn}\end{bmatrix}, \tag{15}$$

where$\aleph_{ij}=$ $\left(8+\left(\theta_{ij}^{T_T}+2\theta_{ij}^{T_I}+\theta_{ij}^{T_F}\right)-\left(\theta_{ij}^{I_T}+2\theta_{ij}^{I_I}+\theta_{ij}^{I_F}\right)-\left(\theta_{ij}^{F_T}+2\theta_{ij}^{F_I}+\theta_{ij}^{F_F}\right)\right)\Big/12;$ $i=1,2\ldots,m;$ $j=1,2,\ldots,n$. Furthermore, the score measures matrix of output factors is generated as follows:

$$\overline{\Re}=\begin{bmatrix} \Re_{11} & \Re_{12} & \Re_{13} & \cdots & \Re_{1n}\\ \Re_{21} & \Re_{22} & \Re_{23} & \cdots & \Re_{2n}\\ \Re_{31} & \Re_{32} & \Re_{33} & \cdots & \Re_{3n}\\ \vdots & \vdots & \vdots & \ddots & \vdots\\ \Re_{m1} & \Re_{m2} & \Re_{m3} & \cdots & \Re_{mn}\end{bmatrix}, \tag{16}$$

where$\Re_{ij}=$ $\left(8+\left(\theta_{ij}^{T_T}+2\theta_{ij}^{T_I}+\theta_{ij}^{T_F}\right)-\left(\theta_{ij}^{I_T}+2\theta_{ij}^{I_I}+\theta_{ij}^{I_F}\right)-\left(\theta_{ij}^{F_T}+2\theta_{ij}^{F_I}+\theta_{ij}^{F_F}\right)\right)\Big/12;$ $i=1,2,\ldots,m;$ $j=1,2,..,n$.

***Step* 8.** Standardization of the elements given in the input and output matrices: elements of both matrices are standardized using Eqs. (17) and (18). The input and output matrices are standardized as done in TOPSIS to acquire normalized matrices (Bansal et al., 2014).

$$P_{ik}=\frac{\aleph_{ij}}{\sqrt{\sum_{i=1}^{l}\aleph_{ik}^{2}}}\qquad(i=1,2,\ldots,l;\ k=1,2,\ldots,K), \tag{17}$$

$$\vartheta_{ik}=\frac{\Re_{ij}}{\sqrt{\sum_{i=1}^{l}\Re_{ij}^{2}}}\qquad(i=1,2,\ldots,l;\ k=1,2,\ldots,K). \tag{18}$$

***Step* 9.** Identify the minimum quantities for each input factor and maximum quantities for each output factor: for inputs, minimum and maximum quantities for output factors are computed using Eqs. (19) and (20):

$$\rho_k^{*}=\min\{\overrightarrow{\rho_k}\}\qquad(k=1,2,\ldots,K), \tag{19}$$

$$\vartheta_j^{*}=\max\{\overrightarrow{\vartheta_j}\}\qquad(j=1,2,\ldots,J). \tag{20}$$

***Step* 10.** Calculating distance measures for inputs and outputs: In this step, distance measures of input and output factors are calculated by implementing Eqs. (21) and (22). While Eq. (21) is used for input factors, Eq. (22) is applied for output factors:

$$i_{pk}=1+\vartheta_{ik}-\vartheta_i^{*}\qquad(k=1,2,\ldots,l;\ k=1,2,\ldots,K), \tag{21}$$

$$o_{pk}=1+\left(\rho_i^{*}-\vartheta_{ij}\right)\qquad(k=1,2,\ldots,l;\ k=1,2,\ldots,K). \tag{22}$$

***Step* 11.** Weighting inputs and outputs: The obtained values in the previous step are weighted with the help of criteria weights computed in the first-four implementation steps. For this purpose, Eqs. (23) and (24) are implemented:

$$f_{is}=\sum_{j=1}^{J}w_i^{i}\times i_{pk}\qquad(i=1,2,\ldots,l;\ k=1,2,\ldots,l;\ k=1,2,\ldots,K), \tag{23}$$

$$f_{os}=\sum_{k=1}^{K}w_i^{o}\times o_{pk}\qquad(i=1,2,\ldots,l;\ k=1,2,\ldots,l;\ k=1,2,\ldots,K). \tag{24}$$

***Step* 12.** Calculating the productivity score of each option: Next, the final performance score of each option is computed by applying Eq. (25). For this purpose, the final input score of each option is segregated into the final output score of the alternative.

$$f_{ps}=\frac{f_{is}}{f_{os}}\qquad(i=1,2,\ldots,l). \tag{25}$$

Then, the alternatives are ranked in descending order with respect to their relative performance scores.

4. Evaluation of the financial and operational performances of the CSCs

Here, the EATWIOS technique based on T2NFNs is implemented to assess the financial and operational performance of global CSCs. This work is concentrated on a real-life evaluation problem encountered by a large-scale freight forwarder company in Turkey. This company is required to select a CSC to carry raw materials supplied from the far east on behalf of its major client (i.e., a large-scale automotive manufacturer in Turkey). However, the company's senior executives were undecided about selecting an appropriate CSC as a strategic partner in the supply chain. Furthermore, they were unsure which factors and criteria should be considered in this evaluation process. They requested our research team to help solve the current problem. We attended a preliminary meeting organized by senior company executives to get more information about the multi-attribute decision problem.

At the end of the meeting, we were sure that it is a highly complicated assessment problem and could only be solved by applying a robust, powerful and practical decision-making model. In addition, a traditional subjective or objective decision-making frame may not work because the maritime industry has a very dynamic structure. Finally, we decided to conduct a research process to provide a logical solution for the selection problem with the senior executives effectively. Besides, researchers had insufficient information about the maritime industry to evaluate the

Table 1
Previous works in the existing literature as well as the used criteria.

Input factors

Code	Criteria	Definition	References
I-1	The Number of Ships	The vessel fleet employed by a shipping company	Bang et al. (2012)
I-2	Countries	The number of countries giving shipping services	Hausman et al (2013)
I-3	The Number of Branches	The number of branches around the world	Kawasaki et al. (2011), Caramia et al. (2007)
I-4	The Number of Owned Containers	The number of containers owned by a shipping company	Contador et al. (2017), Dong and Song (2012), Hoffmann et al. (2020)
I-5	The Number of Lanes	The number of lines operated by a shipping company	Martínez-Zarzoso and Nowak-Lehmann (2007), Wang and Meng (2012)
I-6	Connected Ports	The number of ports given shipping service	Wu et al. (2019), Kang and Woo (2017)
I-7	The Number of Employees	The number of employees: blue and white collars	Chao et al. (2018)
I-8	The Number of Ship Crews	The number of staff responsible for sailing	Chao et al. (2018)
I-9	Total Container Carriage Capacity	The carriage capacity of the fleet in terms of TEU	Chao et al. (2018)
I-10	Average Age of Ships	The average age of the vessels that are in the fleet	Bang et al. (2012)
I-11	Total Current Liabilities / Total Assets	The ratio of current assets to current liabilities	Wang (2014)
I-12	Total Liabilities / Total Assets	The proportion of a company's assets which are financed through debt	Chou and Liang (2001), Lu et al. (2009), Lee et al. (2018), Lee et al. (2014), Lee et al. (2012), Wang and Lee (2010), Wang and Kao (2011)
I-13	Cost of Revenue / Net Sales	The ratio of the incurring costs for revenues to the net sales	Lee et al. (2018), (Lee et al., 2014), Lee et al. (2012), Wang and Lee (2010), Wang and Kao (2011),Wang (2014)
I-14	Operating Expenses / Net Sales	This ratio is computed by dividing total operating expenses by net sales	Decision of the experts
I-15	Assets/Equity	The relationship of the firm' total assets to the part owned by shareholders	Decision of the experts
I-16	Avg. A/R Days	The number of days that a customer invoice is outstanding	Chou and Liang (2001), Wang and Lee (2010), (Wang and Kao (2011), Wang (2014)

Outputs factors

Code	Criteria	Definition	References
O-1	Total Carriage TEU	The actual carriage containers in terms of TEU	Bang et al. (2012)
O-2	Average TEU per Ship	The average number of containers per container vessel	Dragović et al. (2009), McKenna et al. (2012)
O-3	Market Share	It refers to the market share of a shipping company	Lim & Lim (2020), Lirn et al. (2014)
O-4	Current Ratio	Measures a firm's ability to pay short-term obligations	Wang et al. (2014), Lee and Lin (2011), Kang et al. (2016), Chou and Liang (2001), Lu et al. (2009), Lim and Lim (2020), Lee et al. (2018), Lee et al. (2014), Lee et al. (2012), Wang and Lee (2010), Wang and Kao (2011), Wang (2014)
O-5	Asset Turnover	Asset turnover is the ratio of total sales or revenue to average assets	Lu et al. (2009), Kang et al. (2016), Pang and Lu (2018), Lee et al. (2018), Lee et al. (2014), Lee et al. (2014), Lee et al. (2012), Wang and Lee (2010), Wang and Kao (2011), Wang (2014)
O-6	Operating Margin	It is equal to operating income divided by revenue	Chou and Liang (2001), Wang et al. (2014), Wang and Kao (2011)
O-7	EBITDA Margin	A measure of a firm's operating profit as a percentage of its revenue.	Alexandrou et al. (2021), Lu et al. (2009)
O-8	Pretax ROA	The ability of the company to utilize its assets to create profit.	Chou and Liang (2001), Lu et al. (2009), Lim and Lim (2020), Lee et al. (2018), Lee et al. (2014), Wang (2014)
O-9	Pretax ROE	The rate of return on the investment by the stockholders	Lu et al. (2009), Kang et al. (2016), Lim and Lim (2020), Lee et al. (2018), Lee et al. (2014), Lee et al. (2012)

alternatives and criteria. Hence, we decided to form a board of experts consisting of working teams. Each team consists of three highly experienced professionals with extensive knowledge of their fields, such as finance and accounting, operation management, and top management, and each team's captain was a senior executive in a freight forwarder company.

4.1. Preparation process

We identified some criteria to be a team captain: (*i*) having experience in the current field for at least 15 years as top managers or firm owners; (*ii*) being a member of a professional association. Secondly, we determined some criteria to be a member of teams for finance and accounting managers and operation managers: (*i*) having experience in the related fields for at least 15 years as a department manager; (*ii*) being a graduate from a related department (i.e., logistics, business management, finance and accounting) of a reputable university.

At the end of the first meeting, we demanded time to conduct a preliminary investigation of the multi-attribute decision problem and collect more data until the next meeting. During this process, we executed a detailed literature review on this issue and tried to identify the candidates who would be members of the board of experts. In the next meeting, we proposed evaluating the candidates with the firm's top managers. During the second meeting, we evaluated 74 candidates who are managers in different companies in the current industry and eliminated some because they are incompatible with being a member of the board of experts regarding the identified criteria. Finally, we decided to work with 33 professionals with sufficient qualifications to be board members. The details of the professionals are presented in Appendix B (Table A). In the next meeting, we collected the lists prepared by the teams and made the final list by removing the repetitive criteria. Besides, we requested them to give a relative significance score to each criterion from each team captain by conferring with the other team members. After we collected the lists evaluated by experts, we computed each criterion's relative significance score by applying the geometric mean of given scores for each criterion. Finally, we identified the final

Table 2
Identified CSCs as alternatives.

Code	Alternatives	Code	Alternatives
A_1	AP Moeller - Maersk	A_7	Matson Inc
A_2	COSCO Shipping	A_8	Orient Overseas
A_3	Evergreen Marine	A_9	Pacific Basin
A_4	Hapag Lloyd AG	A_{10}	SITC International
A_5	Hyundai Merchant	A_{11}	Wan Hai Lines ltd
A_6	ONE	A_{12}	Yang Ming Marine

Table 3
T2FNN linguistic scale to identify the significance of criteria.

Linguistic variables	T2FNN
Low (L)	[(0.20,0.30,0.20), (0.60,0.70,0.80), (0.45,0.75,0.75)]
Medium Low (ML)	[(0.40,0.30,0.25), (0.45,0.55,0.40), (0.45,0.60,0.55)]
Medium (M)	[(0.50,0.55,0.55), (0.40,0.45,0.55), (0.35,0.40,0.35)]
High (H)	[(0.80,0.75,0.70), (0.20,0.15,0.30), (0.15,0.10,0.20)]
Very High (VH)	[(0.90,0.85,0.95), (0.10,0.15,0.10), (0.05,0.05,0.10)]

criteria by eliminating some criteria with importance scores under three by coming to a consensus among the members. The last input and output criteria are presented in Table 1.

We also determined the alternatives with the corporates' top managers, and the determined alternatives are illustrated in Table 2.

Next, each team executes linguistic assessments for both factors and options by taking into account the linguistic scale demonstrated in Tables 3 and 6. The aggregated linguistic evaluations for the criteria and alternatives are presented in Appendix B (Table B).

4.2. Calculation of the criteria weights

In this phase, we identify the criteria weights by following the basic algorithm of the suggested model.

***Step* 1.** Next, each team executes linguistic assessments for both criteria and alternatives with the help of the T2NFN linguistic evaluation scale given in Table 3.

Then, the linguistic evaluations made by teams for input and output factors are aggregated. The aggregated evaluations are presented in Appendix B (Table C).

***Step* 2.** In this step, we fuse decision-makers' evaluations using Eq. (8). Hence, we compute the relative significances of the criteria concerning the experts' linguistic assessments. Aggregated experts' assessments for the factors and the T2NFN significance factor for criterion *j* are given in Appendix B (Table B).

***Steps* 3–4.** The T2NFN weights for the factors are employed to calculate the score measures of the criteria. Eq. (6) is employed to calculate these values. Next, the computed criteria weights are

Table 6
T2FNN scale to assess the alternatives.

Linguistic variables	T2FNN
Very Bad (VB)	[(0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70)]
Bad (B)	[(0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65)]
Medium Bad (MB)	[(0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60)]
Medium (M)	[(0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45)]
Medium Good (MG)	[(0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15)]
Good (G)	[(0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20)]
Very Good (VG)	[(0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05)]

Table 4
Aggregated expert evaluations of criteria and input criteria weights.

Aggregated Value for Input Factors											
	T			I			F				
Criteria	T	I	F	T	I	F	T	I	F	Sc Vl.	Nr. Vl.
I-1	0.859	0.820	0.876	0.118	0.150	0.136	0.068	0.059	0.118	0.859	0.820
I-2	0.871	0.835	0.898	0.100	0.150	0.100	0.050	0.050	0.100	0.871	0.835
I-3	0.582	0.541	0.518	0.336	0.377	0.386	0.305	0.359	0.359	0.582	0.541
I-4	0.536	0.491	0.455	0.368	0.414	0.414	0.341	0.409	0.400	0.536	0.491
I-5	0.866	0.827	0.889	0.109	0.150	0.118	0.059	0.055	0.109	0.866	0.827
I-6	0.681	0.676	0.676	0.273	0.286	0.377	0.223	0.227	0.250	0.681	0.676
I-7	0.734	0.699	0.699	0.232	0.241	0.300	0.186	0.186	0.232	0.734	0.699
I-8	0.582	0.527	0.514	0.332	0.386	0.355	0.305	0.373	0.368	0.582	0.527
I-9	0.582	0.541	0.518	0.336	0.377	0.386	0.305	0.359	0.359	0.582	0.541
I-10	0.846	0.804	0.844	0.136	0.150	0.173	0.086	0.068	0.136	0.846	0.804
I-11	0.801	0.764	0.772	0.182	0.177	0.250	0.132	0.109	0.177	0.801	0.764
I-12	0.859	0.820	0.876	0.118	0.150	0.136	0.068	0.059	0.118	0.859	0.820
I-13	0.853	0.812	0.861	0.127	0.150	0.155	0.077	0.064	0.127	0.853	0.812
I-14	0.866	0.827	0.889	0.109	0.150	0.118	0.059	0.055	0.109	0.866	0.827
I-15	0.734	0.699	0.699	0.232	0.241	0.300	0.186	0.186	0.232	0.734	0.699
I-16	0.866	0.827	0.889	0.109	0.150	0.118	0.059	0.055	0.109	0.866	0.827

Table 5
Aggregated expert evaluations of output criteria and criteria weights.

Aggregated Value for Input Factors											
	T			I			F				
Criteria	T	I	F	T	I	F	T	I	F	Sc Vl.	Nr. Vl.
O-1	0.809	0.772	0.793	0.173	0.177	0.232	0.123	0.105	0.168	0.8240	0.1243
O-2	0.518	0.482	0.464	0.377	0.441	0.418	0.350	0.432	0.405	0.5542	0.0836
O-3	0.636	0.591	0.550	0.305	0.314	0.373	0.268	0.291	0.323	0.6575	0.0992
O-4	0.681	0.641	0.613	0.273	0.277	0.345	0.232	0.241	0.282	0.7006	0.1057
O-5	0.545	0.500	0.477	0.359	0.414	0.395	0.332	0.405	0.391	0.5757	0.0868
O-6	0.831	0.788	0.805	0.155	0.150	0.209	0.105	0.077	0.155	0.8447	0.1274
O-7	0.742	0.712	0.672	0.236	0.205	0.345	0.186	0.155	0.227	0.7603	0.1147
O-8	0.839	0.796	0.825	0.145	0.150	0.191	0.095	0.073	0.145	0.8528	0.1286
O-9	0.846	0.804	0.844	0.136	0.150	0.173	0.086	0.068	0.136	0.8609	0.1298

Table 7
Normalized input matrix.

	I-1	I-2	I-3	I-4	I-5	I-6	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16
A_1	0.130	0.154	0.138	0.122	0.248	0.309	0.192	0.128	0.133	0.317	0.299	0.400	0.719	0.122	0.337	0.137
A_2	0.147	0.264	0.260	0.258	0.397	0.331	0.129	0.364	0.229	0.247	0.324	0.313	0.221	0.319	0.309	0.156
A_3	0.280	0.348	0.269	0.258	0.397	0.154	0.342	0.315	0.224	0.323	0.231	0.189	0.252	0.324	0.269	0.277
A_4	0.216	0.165	0.157	0.214	0.137	0.259	0.206	0.228	0.232	0.244	0.226	0.307	0.221	0.208	0.292	0.151
A_5	0.304	0.253	0.231	0.341	0.232	0.250	0.336	0.306	0.323	0.247	0.219	0.170	0.215	0.314	0.237	0.260
A_6	0.307	0.154	0.263	0.209	0.143	0.326	0.266	0.218	0.224	0.314	0.229	0.152	0.221	0.285	0.123	0.271
A_7	0.351	0.413	0.417	0.335	0.380	0.408	0.336	0.352	0.359	0.154	0.362	0.155	0.182	0.255	0.275	0.260
A_8	0.322	0.256	0.136	0.301	0.196	0.243	0.296	0.315	0.288	0.314	0.374	0.290	0.182	0.281	0.337	0.256
A_9	0.304	0.436	0.430	0.346	0.401	0.414	0.342	0.210	0.321	0.404	0.374	0.289	0.182	0.324	0.337	0.429
A_{10}	0.351	0.252	0.430	0.346	0.312	0.131	0.342	0.315	0.370	0.241	0.344	0.500	0.182	0.324	0.337	0.443
A_{11}	0.309	0.331	0.256	0.336	0.235	0.240	0.287	0.306	0.367	0.237	0.234	0.307	0.230	0.321	0.337	0.268
A_{12}	0.335	0.267	0.256	0.301	0.186	0.253	0.294	0.313	0.291	0.340	0.127	0.155	0.203	0.314	0.181	0.362

Table 8
Normalized output matrix.

	O-1	O-2	O-3	O-4	O-5	O-6	O-7	O-8	O-9
A_1	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_2	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_3	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_4	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_5	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_6	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_7	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_8	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_9	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_{10}	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_{11}	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202
A_{12}	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202	0.202

determined by performing a standardization operation. The input and output factors' weights and score values are presented in Tables 4 and 5.

For example, the T2NN significance factor for the I1 factor is computed as follows:

$$SF_{C1} = \left[\left(SF_{C1}^{T_T}, SF_{C1}^{T_I}, SF_{C1}^{T_F}\right), \left(SF_{C1}^{I_T}, SF_{C1}^{I_I}, SF_{C1}^{I_F}\right), \left(SF_{C1}^{F_T}, SF_{C1}^{F_I}, SF_{C1}^{F_F}\right)\right] =$$

$$= \begin{cases} SF_{C1}^{T_T} = \{(0.90 + 0.90 + 0.90 + ... + 0.90) - (0.90 \cdot 0.90 \cdot 0.90 \cdot ... \cdot 0.90)\}/11 = 0.859; \\ SF_{C1}^{T_I} = \{(0.85 + 0.85 + 0.80 + ... + 0.85) - (0.85 \cdot 0.85 \cdot 0.80 \cdot ... \cdot 0.85)\}/11 = 0.820; \\ SF_{C1}^{T_F} = \{(0.95 + 0.95 + 0.20 + ... + 0.95) - (0.95 \cdot 0.95 \cdot 0.20 \cdot ... \cdot 0.95)\}/11 = 0.876; \\ SF_{C1}^{I_T} = \{(0.10 + 0.10 + 0.10 + ... + 0.10) - (0.10 \cdot 0.10 \cdot 0.10 \cdot ... \cdot 0.10)\}/11 = 0.118; \\ SF_{C1}^{I_I} = \{(0.15 + 0.15 + 0.15 + ... + 0.15) - (0.15 \cdot 0.15 \cdot 0.15 \cdot ... \cdot 0.15)\}/11 = 0.150; \\ SF_{C1}^{I_F} = \{(0.10 + 0.10 + 0.10 + ... + 0.10) - (0.10 \cdot 0.10 \cdot 0.10 \cdot ... \cdot 0.10)\}/11 = 0.136; \\ SF_{C1}^{F_T} = \{(0.05 + 0.05 + 0.05 + ... + 0.05) - (0.05 \cdot 0.05 \cdot 0.05 \cdot ... \cdot 0.05)\}/11 = 0.068; \\ SF_{C1}^{F_I} = \{(0.05 + 0.05 + 0.05 + ... + 0.05) - (0.05 \cdot 0.05 \cdot 0.05 \cdot ... \cdot 0.05)\}/11 = 0.059; \\ SF_{C1}^{F_F} = \{(0.10 + 0.10 + 0.10 + ... + 0.10) - (0.10 \cdot 0.10 \cdot 0.10 \cdot ... \cdot 0.10)\}/11 = 0.118; \end{cases}$$

$$= [(0.854, 0.820, 0.876), (0.118, 0.150, 0.136), (0.068, 0.059, 0.118)].$$

The following section demonstrates the computation of the score measure of criterion C1 using Eq. (6):

$$S_{C1} = \left(\begin{array}{c} 8 + (0.859 + 2 \cdot 0.820 + 0.876) - (0.118 + 2 \cdot 0.150 + 0.136) \\ -(0.068 + 2 \cdot 0.059 + 0.118) \end{array} \right) \Big/ 12$$

$$= 0.876.$$

The remaining score measures factors are identified similarly. Thus, we calculate the criteria weights using Eq. (9) by applying an additive standardization approach.

4.3. *Analysis of the financial and operational performance of the alternatives*

In this phase, we compute the performance score of each alternative by following the remaining execution steps of the developed model. The implementation of the remaining sections is described as follows:

***Step* 5.** Experts $\xi = \{\xi_1, \xi_2, ..., \xi_{11}\}$ appraise the options using the T2FNN scale given in Table 6 to implement the recommended T2FNN

Table 9
Input distance measures matrix.

	I-1	I-2	I-3	*I*-4	I-5	I-6	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16
A_1	1.000	1.024	1.008	0.992	1.117	1.178	1.062	0.998	1.003	1.187	1.169	1.270	1.589	0.992	1.206	1.007
A_2	1.017	1.134	1.130	1.128	1.267	1.201	0.999	1.233	1.098	1.117	1.194	1.183	1.090	1.189	1.179	1.026
A_3	1.150	1.218	1.139	1.128	1.267	1.024	1.211	1.185	1.094	1.192	1.101	1.059	1.122	1.194	1.139	1.147
A_4	1.086	1.034	1.027	1.084	1.006	1.129	1.076	1.097	1.102	1.114	1.096	1.176	1.090	1.077	1.162	1.021
A_5	1.174	1.123	1.100	1.211	1.102	1.120	1.206	1.176	1.193	1.117	1.089	1.040	1.084	1.183	1.107	1.129
A_6	1.176	1.023	1.133	1.079	1.013	1.195	1.135	1.087	1.094	1.184	1.099	1.022	1.090	1.155	0.993	1.141
A_7	1.220	1.282	1.286	1.205	1.249	1.278	1.206	1.222	1.229	1.024	1.232	1.025	1.052	1.125	1.145	1.130
A_8	1.192	1.126	1.006	1.170	1.065	1.113	1.166	1.185	1.158	1.184	1.244	1.160	1.052	1.151	1.206	1.126
A_9	1.174	1.306	1.300	1.216	1.271	1.284	1.211	1.080	1.191	1.273	1.244	1.159	1.052	1.194	1.206	1.298
A_{10}	1.220	1.122	1.300	1.216	1.182	1.001	1.211	1.185	1.240	1.110	1.213	1.370	1.052	1.194	1.206	1.313
A_{11}	1.178	1.201	1.126	1.205	1.105	1.109	1.157	1.176	1.236	1.106	1.104	1.176	1.099	1.190	1.206	1.137
A_{12}	1.205	1.137	1.126	1.170	1.056	1.123	1.163	1.182	1.161	1.209	0.997	1.024	1.073	1.184	1.051	1.232

Table 10
Output distance measures matrix.

	O-1	O-2	O-3	O-4	O-5	O-6	O-7	O-8	O-9
A_1	1.000	0.825	0.974	0.866	0.778	0.759	0.840	0.823	0.807
A_2	0.815	0.867	0.913	0.664	0.640	0.831	0.927	0.823	0.846
A_3	0.815	0.825	0.793	0.839	0.769	0.764	0.773	0.823	0.846
A_4	0.815	0.867	0.835	0.654	0.775	0.831	0.843	0.818	0.843
A_5	0.813	0.820	0.725	0.856	0.920	0.629	0.633	0.624	0.609
A_6	0.815	0.863	0.799	0.764	0.766	0.663	0.689	0.657	0.654
A_7	0.681	0.649	0.672	0.753	0.811	0.854	0.832	0.849	0.839
A_8	0.801	0.867	0.785	0.919	0.778	0.837	0.757	0.815	0.846
A_9	0.801	0.723	0.785	0.839	0.762	0.864	0.840	0.849	0.835
A_{10}	0.670	0.605	0.662	0.919	0.841	0.916	0.877	0.900	0.846
A_{11}	0.681	0.729	0.785	0.766	0.867	0.836	0.773	0.823	0.843
A_{12}	0.813	0.867	0.793	0.644	0.868	0.752	0.760	0.742	0.720

Table 11
Weighted input distance measures matrix.

	I-1	I-2	I-3	*I*-4	I-5	I-6	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16
A_1	0.070	0.073	0.049	0.045	0.079	0.067	0.064	0.049	0.049	0.082	0.077	0.089	0.111	0.070	0.073	0.071
A_2	0.072	0.081	0.055	0.051	0.090	0.069	0.060	0.060	0.054	0.077	0.078	0.083	0.076	0.084	0.071	0.073
A_3	0.081	0.087	0.056	0.051	0.090	0.059	0.073	0.058	0.054	0.082	0.072	0.075	0.078	0.085	0.069	0.081
A_4	0.076	0.074	0.050	0.049	0.071	0.065	0.065	0.053	0.054	0.077	0.072	0.083	0.076	0.076	0.070	0.072
A_5	0.083	0.080	0.054	0.055	0.078	0.064	0.073	0.057	0.058	0.077	0.071	0.073	0.076	0.084	0.067	0.080
A_6	0.083	0.073	0.056	0.049	0.072	0.068	0.069	0.053	0.054	0.082	0.072	0.072	0.076	0.082	0.060	0.081
A_7	0.086	0.092	0.063	0.055	0.089	0.073	0.073	0.059	0.060	0.071	0.081	0.072	0.073	0.080	0.069	0.080
A_8	0.084	0.081	0.049	0.053	0.076	0.064	0.070	0.058	0.057	0.082	0.081	0.082	0.073	0.082	0.073	0.080
A_9	0.083	0.093	0.064	0.055	0.090	0.074	0.073	0.053	0.058	0.088	0.081	0.082	0.073	0.085	0.073	0.092
A_{10}	0.086	0.080	0.064	0.055	0.084	0.057	0.073	0.058	0.061	0.077	0.079	0.096	0.073	0.085	0.073	0.093
A_{11}	0.083	0.086	0.055	0.055	0.078	0.064	0.070	0.057	0.061	0.076	0.072	0.083	0.077	0.084	0.073	0.081
A_{12}	0.085	0.081	0.055	0.053	0.075	0.064	0.070	0.058	0.057	0.084	0.065	0.072	0.075	0.084	0.063	0.087

Table 12
Weighted output distance measures matrix.

	O-1	O-2	O-3	O-4	O-5	O-6	O-7	O-8	O-9
A_1	0.124	0.069	0.097	0.092	0.068	0.097	0.096	0.106	0.105
A_2	0.101	0.072	0.091	0.070	0.056	0.106	0.106	0.106	0.110
A_3	0.101	0.069	0.079	0.089	0.067	0.097	0.089	0.106	0.110
A_4	0.101	0.072	0.083	0.069	0.067	0.106	0.097	0.105	0.109
A_5	0.101	0.069	0.072	0.090	0.080	0.080	0.073	0.080	0.079
A_6	0.101	0.072	0.079	0.081	0.066	0.084	0.079	0.085	0.085
A_7	0.085	0.054	0.067	0.080	0.070	0.109	0.095	0.109	0.109
A_8	0.100	0.072	0.078	0.097	0.068	0.107	0.087	0.105	0.110
A_9	0.100	0.060	0.078	0.089	0.066	0.110	0.096	0.109	0.108
A_{10}	0.083	0.051	0.066	0.097	0.073	0.117	0.101	0.116	0.110
A_{11}	0.085	0.061	0.078	0.081	0.075	0.107	0.089	0.106	0.109
A_{12}	0.101	0.072	0.079	0.068	0.075	0.096	0.087	0.095	0.093

Table 13
Final inputs, outputs, performance scores and ranking of the alternatives.

	Inputs	Outputs	Performance score	Rank
A_1	1.121	0.852	0.7607	1
A_2	1.136	0.818	0.7204	3
A_3	1.151	0.806	0.7006	5
A_4	1.085	0.810	0.7464	2
A_5	1.131	0.724	0.6398	12
A_6	1.101	0.733	0.6656	10
A_7	1.176	0.778	0.6615	11
A_8	1.144	0.823	0.7191	4
A_9	1.217	0.817	0.6708	9
A_{10}	1.195	0.813	0.6800	7
A_{11}	1.155	0.790	0.6840	6
A_{12}	1.129	0.767	0.6794	8

EATWIOS model for assessing the options$A_i (i = 1, 2, ..., 12)$. Experts' linguistic assessments are demonstrated in Table C.

***Step* 6.** We identify the T2FNN significance of the alternatives concerning the input and output factors with the help of Eq. (8). The T2FN matrix representing the significant factors of the options is presented in Table B. Moreover, the computation of the T2NN significance of Option A1 in regard to input criterion I1 is shown as follows:

$$\theta^{SF}_{A1-I1} = \left[\left(\theta^{T_T}_{11}, \theta^{T_I}_{11}, \theta^{T_F}_{11}\right), \left(\theta^{I_T}_{11}, \theta^{I_I}_{11}, \theta^{I_F}_{11}\right), \left(\theta^{F_T}_{11}, \theta^{F_I}_{11}, \theta^{F_F}_{11}\right)\right]$$

$$= \begin{cases} \theta^{T_T}_{11} = \{(0.35 + 0.20 + 0.20 + ... + 0.95) - (0.35 \cdot 0.20 \cdot 0.20 \cdot ... \cdot 0.95)\}/11 = 0.350; \\ \theta^{T_I}_{11} = \{(0.35 + 0.20 + 0.20 + ... + 0.90) - (0.35 \cdot 0.20 \cdot 0.20 \cdot ... \cdot 0.90)\}/11 = 0.327; \\ \theta^{T_F}_{11} = \{(0.10 + 0.10 + 0.10 + ... + 0.95) - (0.10 \cdot 0.10 \cdot 0.10 \cdot ... \cdot 0.95)\}/11 = 0.214; \\ \theta^{I_T}_{11} = \{(0.75 + 0.80 + 0.80 + ... + 0.10) - (0.75 \cdot 0.80 \cdot 0.80 \cdot ... \cdot 0.10)\}/11 = 0.677; \\ \theta^{I_I}_{11} = \{(0.75 + 0.80 + 0.80 + ... + 0.10) - (0.75 \cdot 0.80 \cdot 0.80 \cdot ... \cdot 0.10)\}/11 = 0.677; \\ \theta^{I_F}_{11} = \{(0.80 + 0.85 + 0.85 + ... + 0.05) - (0.80 \cdot 0.85 \cdot 0.85 \cdot ... \cdot 0.05)\}/11 = 0.722; \\ \theta^{F_T}_{11} = \{(0.50 + 0.45 + 0.45 + ... + 0.05) - (0.50 \cdot 0.45 \cdot 0.45 \cdot ... \cdot 0.05)\}/11 = 0.432; \\ \theta^{F_I}_{11} = \{(0.75 + 0.80 + 0.80 + ... + 0.05) - (0.75 \cdot 0.80 \cdot 0.80 \cdot ... \cdot 0.05)\}/11 = 0.668; \\ \theta^{F_F}_{11} = \{(0.65 + 0.70 + 0.70 + ... + 0.05) - (0.65 \cdot 0.70 \cdot 0.70 \cdot ... \cdot 0.05)\}/11 = 0.614; \end{cases}$$

$$= [(0.350, 0.324, 0.214), (0.677, 0.677, 0.722), (0.432, 0.668, 0.614)].$$

Identically, we identify the remaining values of the T2NN significance factor of the alternatives.

***Steps* 7–8.** The score measure of options is determined using Eq. (6), and an aggregated basic T2NN decision matrix is built up (cf. Table 8). The computation of the score measure of alternative A1 based on I1 is displayed as follows:

$$S_{A1-I1} = \left(\begin{array}{c} 8 + (0.350 + 2 \cdot 0.324 + 0.214) - (0.677 + 2 \cdot 0.677 + 0.722) \\ -(0.432 + 2 \cdot 0.668 + 0.614) \end{array} \right) \Big/ 12$$
$$= 0.340.$$

***Step* 9.** Here, the initial T2NFN input and output matrices are generated, and the elements of both matrices are standardized by implementing Eqs. (17) and (18). The normalized input and output matrices are presented in Tables 7 and 8.

***Step* 10.** We identify the input factors' minimum values and output factors' maximum values using Eqs. (19) and (20).

***Step* 11.** Next, we employ the mathematical expressions of Eqs. (21) and (22) to compute distance measures of the inputs and outputs. The values are presented in Tables 9 and 10.

***Step* 12.** In this step, we weight the distance scores of inputs and outputs using Eqs. (22) and (23). The weighted input and output matrices are given in Tables 11 and 12.

***Step* 13.** By applying Eq. (23), we identify the overall performance score of each option. For this purpose, we divide the sum of inputs into the sum of outputs of each option.

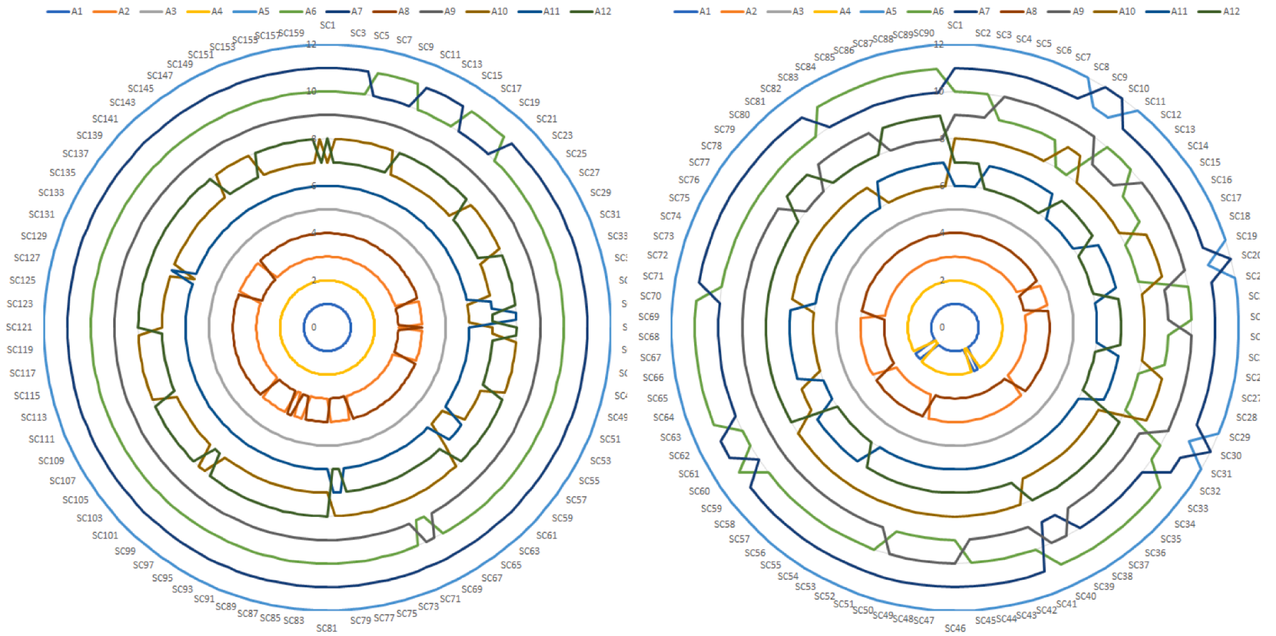
As shown in Table 13, A1 AP Moeller – Maersk is the most efficient CSC with higher financial and operational performance than others. When we examine the crisp data about the shipping company, AP Moeller – Maersk is the most dominant CSC in the global shipping market with a market share of 17 % despite its reasonable number of containers and lines (i.e., less than many competitors of this company). Hence, it proves that the company can carry out its shipping activities with a higher performance and productivity compared to the others. However, the company excessively uses intensive human force as white-collar staff and ship crews. The number of employees of this company is higher than other companies by 13.12 % on average. It may be a critical factor in reducing the company's productivity, and practitioners in the company should consider it.

In addition, the input values of the company are not minimum compared to the others, but it has reached higher output values than others. Hence, it shows that focusing on the outputs instead of inputs can provide higher efficiency and can help to increase the overall performance of CSCs. The next section executes a sensitivity analysis consisting of three phases to assess the proposed model's validity, effectiveness, and practicability.

4.4. Validation test

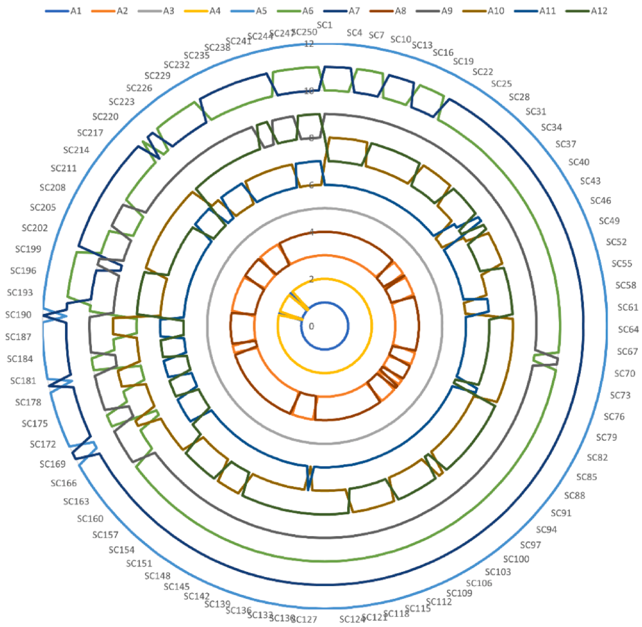
Here, we test the validity and applicability of the T2NFN EATWIOS approach by performing a robustness test consisting of three stages. In the first stage, we examine the consistency and stability of the model by making excessive changes on the criteria weights. In the second phase, we compare the developed model results with the results of different performance analysis frameworks. Moreover, we check the resistance of the model to the rank reversal. The implementations of these phases are presented as follows.

a. Check the impacts of changing input and output criteria weights on the ranking results: In this phase, we change all criteria weights by following the algorithm introduced by Görçün et al. (2021). We decided to implement this approach as it considers all possible effects of changes in



a. Re-ranking of alternatives for changing the input criteria weights

b. Re-ranking of the options for changing the output criteria



c. Re-ranking of alternatives for changing the input and output criteria weights

Fig. 2. Re-ranking of alternatives and options.

criteria weights on the overall ranking results. In this respect, 250 scenarios are generated, and both input and output criteria weights are changed, respectively.

$$w^1_{fv} = w^1_{pv} - \left(w^1_{pv} \times m_v\right) \tag{26}$$

$$w^2_{nv} = \frac{\left(1 - w^1_{fv}\right)}{n-1} + w^2_{pv}, \tag{27}$$

$$w^1_{fv} + \sum w^2_{nv} = 1 \tag{28}$$

Here, w^1_{fv} demonstrates the modified weight of the j^{th} factor' new value, w^1_{pv} is the criterion's initial value, m_v is the modification degree in terms of percentage (i.e., 10 %, 20 %,…,100 %). Moreover, w^2_{nv} denotes new values of remaining factors, n is the factors number, w^2_{pv} is the remaining criteria' previous value.

The obtained results are elaborately presented in Fig. 2a and b. When Fig. 2a and b are evaluated in detail, changing the output criteria impacts the ranking results more than modifications of the input criteria. While A1, as the best alternative, remains in the same rank for 85 out of 90 scenarios formed by modifying the output criteria, its ranking position has never changed in all 160 scenarios concerning input criteria changes. In addition, the ranking positions of A3, A4, and A5 alternatives had not changed when the input criteria weights are changed.

Here, the similarity coefficient between the original ranking result and the acquired re-ranking result in each scenario is computed, and the

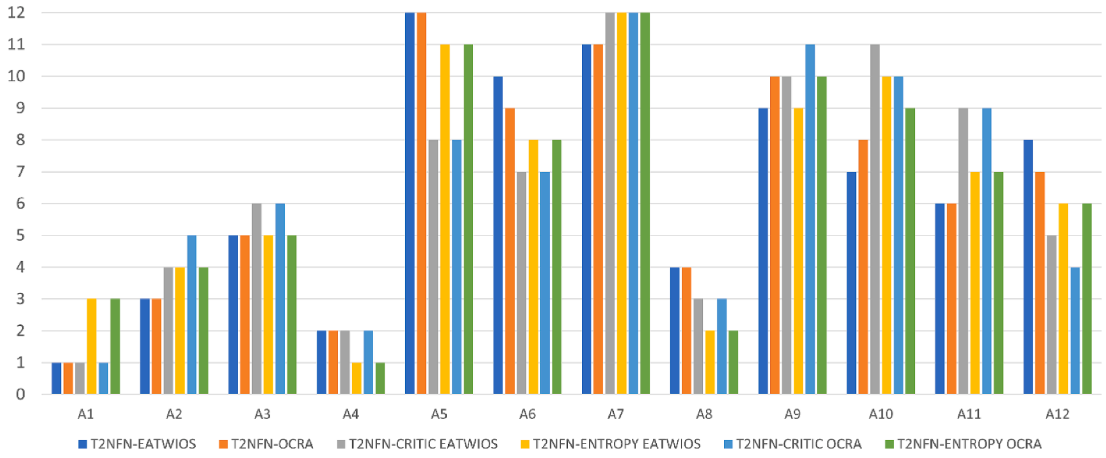


Fig. 3. Ranking of the alternatives related to the implemented T2NFN MCDM methods.

Table 14
Correlation coefficients of all T2NFN MCDM methods.

		T2NFN					
		EATWIOS	OCRA	CRITIC-EATWIOS	ENTROPY-EATWIOS	CRITIC-OCRA	ENTROPY-OCRA
T2NFN	EATWIOS	1.000	0.986	0.776	0.895	0.755	0.909
	OCRA	0.986	1.000	0.839	0.930	0.825	0.944
	CRITIC EATWIOS	0.776	0.839	1.000	0.916	0.986	0.909
	ENTROPY EATWIOS	0.895	0.930	0.916	1.000	0.895	0.993
	CRITIC OCRA	0.755	0.825	0.986	0.895	1.000	0.902
	ENTROPY OCRA	0.909	0.944	0.909	0.993	0.902	1.000
Average correlation coefficient value							0.915

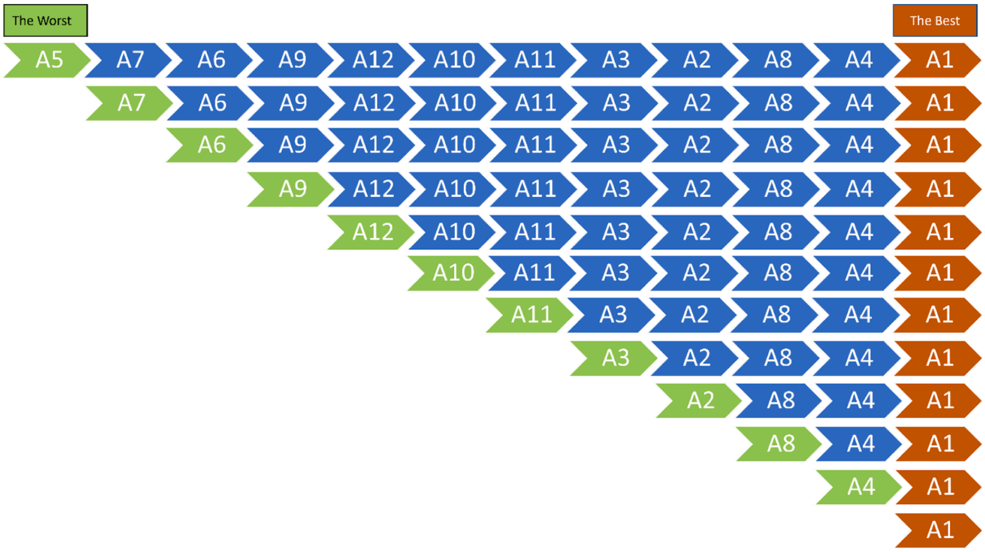


Fig. 4. Resistance of the suggested T2NFN model to rank reversal problem.

average similarity coefficient value is computed by employing the arithmetic mean of these similarity coefficients. While the average similarity coefficient is computed as 0.866 concerning the first 160 scenarios formed by changing the input criteria, this value is calculated as 0.677 for the scenarios generated by modifying the weights of the output criteria. Furthermore, when the I6 input factor's weight is reduced by over 60 % and others' weights are reduced by over 90 %, the ranking performances of some alternatives are changed. These modifications can be accepted as excessive, and the possibility of occurrences of these changes is extremely low in real-life conditions. Moreover, when the weight of O9, the most influential output criteria, is changed by over 40 %, and others' weights are changed by over 70 %, some deviations in the ranking results are observed. Therefore, the output factors are more sensitive to the changing criteria weights than the input criteria. However, they are slight modifications, which cannot influence the overall results in spite of excessive changes. As understood

Table A
Details of the members of the experts board.

Team	DMs	Role	Graduate	Duty	EXP.	Country
T-1	DM-1.1	Team captain	Industrial Eng.	Board Chairman	21	Turkey
	DM-1.2	Operation Manager	Maritime Trans. Eng.	Vessel Operation Man.	16	Turkey
	DM-1.3	Finance Manager	Finance Management	Finance and Accounting Man.	17	Turkey
T-2	DM-2.1	Team captain	Maritime Trans. Eng.	Vice-Board Chairman	23	Turkey
	DM-2.2	Operation Manager	Managing Director	Vessel Operation Man.	19	Turkey
	DM-2.3	Finance Manager	Business Management	Finance and Accounting Man.	15	Turkey
T-3	DM-3.1	Team captain	Business Management	CEO	17	Germany
	DM-3.2	Operation Manager	Logistics Management	Container Shipping Man.	18	Germany
	DM-3.3	Finance Manager	Economics	Finance Man.	16	Germany
T-4	DM-4.1	Team captain	Transport Management	Company Owner	24	Turkey
	DM-4.2	Operation Manager	Maritime Transportation	Line Man.	16	Turkey
	DM-4.3	Finance Manager	Finance Management	Accounting Man.	17	Turkey
T-5	DM-5.1	Team captain	Economics	Member of board	19	Turkey
	DM-5.2	Operation Manager	Transport Management	Operation Man.	21	Turkey
	DM-5.3	Finance Manager	Business Management	Accounting Man.	17	Turkey
T-6	DM-6.1	Team captain	Business Management	Member of board	16	Belgium
	DM-6.2	Operation Manager	Transport Management	Operation Man.	15	Belgium
	DM-6.3	Finance Manager	Business Management	Finance Man.	19	Belgium
T-7	DM-7.1	Team captain	Management	Vice-Board Chairman	27	Italy
	DM-7.2	Operation Manager	Logistics Management	Branch Man.	16	Italy
	DM-7.3	Finance Manager	Accounting	Accounting Man.	21	Italy
T-8	DM-8.1	Team captain	Industrial Eng.	Member of board	19	Russia
	DM-8.2	Operation Manager	Transport Management	Operation Man.	21	Russia
	DM-8.3	Finance Manager	Accounting	Finance Man.	16	Russia
T-9	DM-9.1	Team captain	Transport Management	Member of board	18	Turkey
	DM-9.2	Operation Manager	Transport Management	Head of Operations	16	Turkey
	DM-9.3	Finance Manager	Accounting	Finance and Accounting Man.	17	Turkey
T-10	DM-10.1	Team captain	Industrial Eng.	Vice-Board Chairman	20	Turkey
	DM-10.2	Operation Manager	Transport Management	Operation and Port Man.	19	Turkey
	DM-10.3	Finance Manager	Business Management	Accounting Man.	18	Turkey
T-11	DM-11.1	Team captain	Industrial Eng.	Vice-Board Chairman	17	Israel
	DM-11.2	Operation Manager	Transport Management	Container Fleet Coordinator	19	Israel
	DM-11.3	Finance Manager	Economics	Finance and Accounting Man.	20	Israel

Table B
Selection criteria and their relative significance scores.

		Teams										
Code	Criteria	1	2	3	4	5	6	7	8	9	10	11
Input factors												
I-1	The Number of Ships	VH	VH	L	M	VH	M	L	M	VH	VH	VH
I-2	Countries	M	VH	VH	VH	VH	H	VH	H	VH	VH	VH
I-3	The Number of Branches	H	VH	VH	H	VH	M	VH	H	L	L	M
I-4	The Number of Owned Containers	VH	VH	VH	VH	VH	M	H	H	ML	M	VH
I-5	The Number of Lanes	M	VH	VH	M	VH	M	VH	H	ML	ML	VH
I-6	Connected Ports	M	H	VH	VH	VH	VH	VH	VH	VH	VH	VH
I-7	The Number of Employees	VH	H	VH	VH	M	M	VH	M	VH	VH	VH
I-8	The Number of Ship Crews	VH	H	VH	H	H	H	H	H	M	M	M
I-9	Total Container Carriage Capacity	H	H	VH	VH	M	H	VH	H	L	L	VH
I-10	Average Age of Ships	VH	VH	VH	VH	VH	H	H	H	H	H	VH
I-11	Total Current Liabilities / Total Assets	H	M	VH	VH	VH	VH	VH	H	VH	VH	VH
I-12	Total Liabilities / Total Assets	H	M	L	VH	M	VH	L	VH	VH	VH	M
I-13	Cost Of Revenue / Net Sales	M	ML	M	M	VH	ML	ML	ML	VH	VH	VH
I-14	Operating Expenses / Net Sales	H	ML	ML	M	M	M	ML	ML	VH	VH	VH
I-15	Assets/Equity	H	ML	L	M	M	ML	ML	ML	VH	VH	VH
I-16	Avg. A/R Days	M	L	ML	M	M	ML	ML	ML	VH	VH	VH
Output factors												
O-1	Total Carriage TEU	VH	L	M	VH	VH	M	M	M	ML	ML	M
O-2	Average TEU per Ship	H	L	M	VH	VH	H	M	H	H	H	M
O-3	Market Share	H	L	VH	VH	M	VH	VH	VH	H	H	VH
O-4	Current Ratio	M	L	VH	VH	M	VH	VH	VH	VH	VH	VH
O-5	Asset Turnover	VH	L	VH	VH	L	M	VH	M	M	M	VH
O-6	Operating Margin	H	L	VH	VH	M	M	VH	M	VH	VH	M
O-7	EBITDA Margin	M	L	VH	ML	M	H	VH	H	L	L	VH
O-8	Pretax ROA	VH	L	M	ML	M	M	M	M	L	L	VH
O-9	Pretax ROE	VH	L	VH	H	VH	VH	VH	VH	VH	VH	VH

from Fig. 3c, when the results obtained for both inputs and outputs are combined, the average similarity ratio is identified as 0.798, which is a high value.

The results obtained in the first stage of the validation test show that the stability and consistency of the suggested model are substantially satisfactory. Accordingly, it is realized that the suggested model gives a

Table C

DMs' linguistic evaluations for decision alternatives.

		I-1	I-2	I-3	I-4	I-5	I-6	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16	O-1	O-2	O-3	O-4	O-5	O-6	O-7	O-8	O-9
P1	DM1	B	B	B	B	M	MG	MB	B	B	MG	MG	MG	VG	B	VG	B	VG	G	VG	G	MB	M	MG	MG	G
P1	DM2	VB	B	B	B	M	MG	MB	B	B	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM3	VB	B	B	B	M	MG	MB	B	B	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM4	B	B	VB	B	M	MG	MB	B	B	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM5	VB	B	VB	B	M	MG	MB	B	B	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM6	B	B	VB	B	M	MG	MB	B	B	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM7	VB	VB	VB	VB	M	MG	MB	VB	VB	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM8	MB	VB	VB	VB	M	M	MB	VB	VB	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM9	B	VB	VB	VB	M	M	B	VB	VB	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM10	VB	VB	VB	VB	M	M	B	VB	B	MG	MG	MG	VG	B	VG	VB	VG	G	VG	G	MB	M	MG	MG	G
P1	DM11	VG	VG	G	VG	VG	VG	G	VG	VG	G	VG	VG	G	VG	VG	G	VG	VG	VG	G	VG	G	MG	VG	VG
P2	DM1	M	MB	M	MG	VG	MG	B	VG	M	MB	G	MB	VB	VG	VG	B	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM2	MB	MB	M	MG	VG	MG	B	VG	M	MB	G	MB	VB	VG	VG	B	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM3	MB	MB	M	MG	VG	MG	B	VG	M	MB	G	MB	VB	VG	VG	B	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM4	B	M	M	MG	VG	MG	B	VG	M	MB	G	MB	VB	VG	G	B	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM5	VB	M	M	MG	VG	MG	B	VG	M	MB	G	MB	VB	VG	G	B	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM6	VB	M	M	MG	VG	MG	B	VG	M	MB	G	MB	VB	VG	G	B	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM7	VB	M	M	MG	VG	MG	B	VG	M	MB	G	MB	VB	VG	G	VB	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM8	VB	M	M	M	VG	MG	B	VG	M	MB	G	MB	VB	VG	G	VB	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM9	VB	M	M	M	VG	MG	B	VG	M	MB	G	MB	VB	VG	G	VB	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM10	B	M	M	M	VG	MG	B	VG	M	MB	G	MB	VB	VG	G	VB	M	VG	G	B	VB	MG	VG	MG	VG
P2	DM11	VG	G	G	VG	G	VG	VG	VG	VG	G	G	VG	G	MG	VG	VG	VG	VG	G	G	MG	G	G	VG	VG
P3	DM1	MG	MG	MB	MG	VG	B	VG	G	M	MG	M	B	VB	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM2	MG	MG	MB	MG	VG	B	VG	G	M	MG	M	B	B	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM3	MG	MG	MB	MG	VG	B	VG	G	M	MG	M	B	B	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM4	MG	MG	MB	MG	VG	B	VG	G	M	MG	M	B	B	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM5	MG	MG	MB	MG	VG	B	VG	G	M	MG	M	B	B	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM6	MG	MG	MB	MG	VG	B	VG	G	M	MG	M	B	B	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM7	MG	MG	MB	MG	VG	B	VG	G	M	MG	M	B	VB	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM8	MG	MG	MB	M	VG	B	VG	G	M	MG	M	B	VB	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM9	MG	MG	MB	M	VG	B	VG	G	M	MG	M	B	VB	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM10	MG	MG	MB	M	VG	VB	VG	G	M	MG	M	B	VB	VG	MG	MB	M	G	M	MG	M	M	M	MG	VG
P3	DM11	VG	VG	VG	VG	G	VG	VG	G	G	VG	VG	VG	VG	VG	VG	VG	VG	VG	G	VG	G	VG	VG	VG	VG
P4	DM1	M	B	B	M	B	MB	M	MB	MB	M	M	MB	VB	MG	G	B	M	VG	MG	B	M	MG	MG	MG	VG
P4	DM2	M	B	B	M	B	MB	M	MB	MB	M	M	MB	VB	MG	G	B	M	VG	MG	B	M	MG	MG	MG	VG
P4	DM3	M	B	B	M	B	MB	M	MB	MB	M	M	MB	VB	M	G	B	M	VG	MG	B	M	MG	MG	MG	VG
P4	DM4	M	B	B	M	B	MB	M	MB	MB	M	M	MB	VB	M	G	B	M	VG	MG	B	M	MG	MG	MG	VG
P4	DM5	M	B	B	M	B	MB	M	MB	MB	M	M	MB	VB	M	G	B	M	VG	MG	B	M	MG	MG	MG	VG
P4	DM6	M	B	B	M	B	MB	M	MB	MB	M	M	MB	VB	M	G	B	M	VG	M	B	M	MG	MG	MG	VG
P4	DM7	M	B	B	M	VB	MB	M	MB	MB	M	M	MB	VB	M	G	VB	M	VG	M	VB	M	MG	MG	MG	VG
P4	DM8	M	B	B	M	VB	MB	M	MB	MB	M	M	MB	VB	M	G	VB	M	VG	M	VB	M	MG	MG	MG	VG
P4	DM9	M	B	B	M	VB	MB	M	MB	MB	M	M	MB	VB	M	G	VB	M	VG	M	VB	M	MG	MG	MG	VG
P4	DM10	M	B	B	M	VB	MB	M	MB	MB	M	M	MB	VB	M	G	VB	M	VG	M	VB	M	MG	MG	MG	VG
P4	DM11	VG	VG	G	VG	G	VG	G	VG	VG	G	G	G	G	G	G	G	VG	VG	G	G	VG	G	G	G	G
P5	DM1	G	MB	MB	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	MG	MB	MB	G	MB	G	VG	VB	VB	VB	VB
P5	DM2	G	MB	MB	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	MG	MB	MB	G	MB	G	VG	VB	VB	VB	VB
P5	DM3	G	MB	MB	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	MG	MB	MB	G	MB	G	VG	VB	VB	VB	VB
P5	DM4	G	MB	MB	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	MG	MB	MB	G	MB	G	VG	VB	VB	VB	VB
P5	DM5	G	M	MB	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	MG	MB	MB	G	MB	G	VG	VB	VB	VB	VB
P5	DM6	G	M	MB	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	MG	MB	MB	G	B	G	VG	VB	VB	VB	VB
P5	DM7	G	M	MB	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	MG	MB	MB	G	VB	G	VG	VB	VB	VB	VB

(*continued on next page*)

Table C (*continued*)

		I-1	I-2	I-3	I-4	I-5	I-6	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16	O-1	O-2	O-3	O-4	O-5	O-6	O-7	O-8	O-9
P5	DM8	G	M	MB	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	M	MB	MB	G	VB	G	VG	VB	VB	VB	VB
P5	DM9	G	M	B	VG	M	MB	VG	G	G	MB	MB	B	VB	VG	M	MB	MB	G	VB	G	VG	VB	VB	VB	VB
P5	DM10	G	M	B	VG	M	MB	VG	G	VG	MB	MB	B	VB	VG	M	MB	MB	G	VB	G	VG	VB	VB	VB	VB
P5	DM11	G	M	M	MG	M	MG	MG	M	MG	G	M	M	MG	M	M	M	G	G	MG	M	M	M	M	M	M
P6	DM1	MG	B	MB	M	B	MG	MG	MB	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	B	B	B
P6	DM2	MG	B	MB	M	B	MG	MG	MB	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	B	B	B
P6	DM3	MG	B	MB	M	B	MG	MG	MB	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	B	B	B
P6	DM4	MG	B	MB	M	B	MG	MG	M	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	B	B	B
P6	DM5	G	B	MB	M	B	MG	MG	M	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	B	B	B
P6	DM6	G	B	MB	M	B	MG	MG	M	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	B	B	B
P6	DM7	G	VB	MB	M	B	MG	MG	M	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	B	B	B
P6	DM8	G	VB	MB	M	B	MG	MG	M	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	B	B	B
P6	DM9	VG	B	MB	M	B	MG	MG	M	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	MB	B	MB
P6	DM10	VG	B	MB	M	B	MG	MG	M	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	M	B	MB	B	MB
P6	DM11	VG	G	G	G	MG	G	MG	MG	MG	MG	G	G	G	VG	G	G	VG	G	VG	G	MG	G	G	G	G
P7	DM1	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	MG	G	MG	G	VG
P7	DM2	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	MG	G	MG	G	VG
P7	DM3	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	MG	G	MG	G	VG
P7	DM4	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	MG	G	MG	G	VG
P7	DM5	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	MG	G	MG	G	VG
P7	DM6	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	MG	G	MG	G	VG
P7	DM7	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	MG	G	MG	G	VG
P7	DM8	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	M	G	MG	G	VG
P7	DM9	VG	VG	VG	VG	VG	VG	VG	VG	VG	B	VG	B	VB	MG	G	MB	B	B	B	MB	M	G	MG	G	VG
P7	DM10	VG	VG	VG	VG	VG	VG	VG	VG	VG	MB	VG	B	VB	MG	G	MB	B	B	B	MB	M	G	MG	G	G
P7	DM11	VG	B	MB	M	B	MG	MG	M	MB	MG	MB	VB	VB	G	B	MB	M	VG	M	MB	MB	MB	M	G	G
P8	DM1	G	MB	B	G	MB	MB	G	G	MG	MG	VG	MB	VB	G	VG	M	MB	VG	MB	VG	MB	MG	M	MG	VG
P8	DM2	G	MB	B	G	MB	MB	G	G	MG	MG	VG	MB	VB	G	VG	M	MB	VG	MB	VG	MB	MG	M	MG	VG
P8	DM3	G	MB	B	G	MB	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	MB	MG	M	MG	VG
P8	DM4	G	MB	B	G	MB	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	MB	MG	M	MG	VG
P8	DM5	G	MB	B	G	MB	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	MB	MG	M	MG	VG
P8	DM6	G	MB	B	G	MB	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	MB	G	M	MG	VG
P8	DM7	G	MB	B	G	MB	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	MB	G	M	MG	VG
P8	DM8	VG	MB	B	G	B	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	MB	G	M	MG	VG
P8	DM9	VG	MB	B	G	B	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	MB	G	M	MG	VG
P8	DM10	VG	MB	B	G	B	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	MB	G	M	MG	VG
P8	DM11	VG	MB	B	G	B	MB	G	G	MG	MG	VG	M	VB	G	VG	M	MB	VG	MB	VG	VG	MB	M	MG	VG
P9	DM1	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	VG
P9	DM2	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	VG
P9	DM3	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	VG
P9	DM4	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	VG
P9	DM5	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	VG
P9	DM6	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	VG
P9	DM7	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	VG
P9	DM8	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	VG
P9	DM9	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	G
P9	DM10	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	VG	MB	MB	MB	MG	MB	G	MG	G	G
P9	DM11	G	VG	VG	VG	VG	VG	VG	M	G	VG	VG	M	VB	VG	VG	M	MB	MB	MB	VG	MB	G	MG	G	G
P10	DM1	VG	M	VG	VG	MG	B	VG	G	VG	M	VG	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM2	VG	M	VG	VG	MG	B	VG	G	VG	M	VG	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM3	VG	M	VG	VG	MG	B	VG	G	VG	M	VG	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM4	VG	M	VG	VG	MG	B	VG	G	VG	M	VG	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG

(*continued on next page*)

Table C (*continued*)

		I-1	I-2	I-3	I-4	I-5	I-6	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16	O-1	O-2	O-3	O-4	O-5	O-6	O-7	O-8	O-9
P10	DM5	VG	M	VG	VG	MG	B	VG	G	VG	M	G	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM6	VG	M	VG	VG	MG	B	VG	G	VG	M	G	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM7	VG	M	VG	VG	MG	B	VG	G	VG	M	G	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM8	VG	M	VG	VG	MG	B	VG	G	VG	M	G	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM9	VG	M	VG	VG	MG	B	VG	G	VG	M	G	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM10	VG	M	VG	VG	MG	B	VG	G	VG	M	G	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P10	DM11	VG	M	VG	VG	MG	B	VG	G	VG	MG	G	VG	VB	VG	VG	VG	B	VB	B	VG	MG	VG	G	VG	VG
P11	DM1	G	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	MG	MG	M	MG	VG
P11	DM2	G	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	MG	MG	M	MG	VG
P11	DM3	G	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	MG	MG	M	MG	VG
P11	DM4	G	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	MG	MG	M	MG	VG
P11	DM5	G	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	MG	MG	M	MG	VG
P11	DM6	G	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	G	MG	M	MG	VG
P11	DM7	G	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	G	MG	M	MG	VG
P11	DM8	VG	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	G	MG	M	MG	VG
P11	DM9	VG	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	G	MG	M	MG	VG
P11	DM10	VG	MG	M	VG	MB	M	G	G	VG	MB	MB	MB	VB	VG	VG	M	B	MB	MB	M	G	MG	M	MG	VG
P11	DM11	M	MB	MG	MB	MB	MB	M	MB	G	M	VG	G	VG	G	VG	G	M	MG	M	VG	VG	VG	VG	VG	G
P12	DM1	G	MB	M	G	MB	MB	G	G	MG	G	B	VB	VB	VG	MB	MG	MB	VG	MB	B	G	MB	MB	MB	M
P12	DM2	G	MB	M	G	MB	MB	G	G	MG	G	B	VB	VB	VG	MB	MG	MB	VG	MB	B	G	MB	MB	MB	M
P12	DM3	G	MB	M	G	MB	MB	G	G	MG	G	B	VB	VB	VG	MB	MG	MB	VG	MB	B	G	MB	MB	MB	M
P12	DM4	VG	MB	M	G	MB	MB	G	G	MG	G	B	VB	VB	VG	MB	G	MB	VG	MB	B	G	MB	MB	MB	M
P12	DM5	VG	MB	M	G	B	MB	G	G	MG	G	B	VB	VB	VG	MB	G	MB	VG	MB	B	G	MB	MB	MB	M
P12	DM6	VG	MB	M	G	B	MB	G	G	MG	G	B	B	VB	VG	MB	G	MB	VG	MB	B	G	MB	MB	MB	M
P12	DM7	VG	MB	M	G	B	MB	G	G	MG	G	B	B	VB	VG	MB	G	MB	VG	MB	VB	G	MB	MB	MB	M
P12	DM8	VG	MB	M	G	B	MB	G	G	MG	G	B	B	VB	VG	MB	G	MB	VG	MB	VB	G	MB	MB	MB	M
P12	DM9	VG	MB	M	G	B	M	G	G	MG	G	B	B	VB	VG	B	G	MB	VG	MB	VB	G	MB	MB	MB	MG
P12	DM10	VG	MB	M	G	B	M	G	G	MG	G	B	B	VB	VG	B	G	MB	VG	MB	VB	G	MB	MB	MB	MG
P12	DM11	G	G	MG	G	G	G	MG	MG	G	M	MB	M	MB	MB	MB	MB	G	VG	MG	M	M	MB	M	MB	MB

trustworthy assessment environment for practitioners.

b. Comparison between the results of proposed model and implemented approaches: In this stage, the results of the T2NFN-EATWIOS approach are compared with the results of the T2NFN-based Operational Competitiveness Rating (OCRA) approach called T2NFN-OCRA (Parkan, 1994), which is another performance analysis technique. Moreover, we combine both T2NFN approaches with some objective weighting techniques such as Criteria Importance through Intercriteria Correlation (CRITIC) (Diakoulaki et al., 1995) and Entropy (Shannon, 1948). In addition to the proposed model, five T2NFN combinations are implemented. The comparison results are demonstrated in Fig. 3.

As shown in Fig. 3, the obtained ranking results are closer on a vast scale except for some integrated T2NFN models by combining with the entropy technique. Next, we compute the correlation coefficient between each pair of the T2NFN model. The obtained results and average correlation coefficient value are presented in Table 14.

As seen in Table 14, the results of T2NFNOCRA are compatible with the proposed model, and there are no severe and significant differences among the results of the implemented models and combinations. It proves that the recommended T2NFN model provides accurate, reliable, and reasonable results.

c. Test the resistance of the proposed model to the rank reversal problem: In the third stage, we check the resistance of the suggested T2NFN model to the rank reversal problem. In these circumstances, we form 11 scenarios and remove the worst alternative in each scenario. Then, we repeat the computations for the remaining alternatives. The obtained results are given in Fig. 4.

When the obtained results are evaluated, only a slight change in the ranking positions of Options A2 and A8 is observed, where no change is observed in the ranking performances of the remaining alternatives. Moreover, A1 remains in the same rank for all scenarios as the best option. These results prove that the offered T2NFN model is a maximally consistent and stable decision-making method, as it is resistant to the rank reversal problem. Even excessively changing the number of alternatives does not significantly affect the suggested model's ranking results.

In conclusion, the results of all phases of the sensitivity analysis demonstrate the validity, robustness, and practicability of the developed T2NFN-EATWIOS method. Thus, the recommended T2NFN model reveals a trustworthy and applicable decision-making environment to the practitioners and can be implemented to solve highly complicated multi-attribute decision problems in numerous fields such as business, engineering, logistics, and transportation aside from the maritime industry.

5. Discussion and outlook

The developed model combines the superiorities of NN, T2Fs, and the EATWIOS approach. Hence, the T2NFN-EATWIOS approach can help make more rational, reasonable, and logical performance analyzes for practitioners in various industries. Besides, it captures and processes many complicated uncertainties that are predictable and unpredictable. Thus, it can easily overcome many ambiguities. When the dynamic structure of the maritime industry that causes many complex uncertainties is considered, the proposed model presents a more unfixed and realistic evaluation environment to the practitioners and executives who are in the maritime industry. Furthermore, the T2NFN model can be implemented to solve many complicated multi-attribute decision problems encountered in the container shipping industry. Furthermore, our findings can be considered by decision-makers as a roadmap to improve their competitiveness and abilities.

Even though the current research has many conceptual contributions and managerial decision aids, there are some constraints in the current study. First, it only deals with CSCs' performance and does not consider the performance of other shipping industries such as dry bulk, Ro-Ro shipping, and tanker shipping. Secondly, it evaluates large-scale global container shippers and does not consider small and regional shipping companies. In addition, some macroeconomic criteria have been descoped, as it only evaluates the financial and operational performance of the CSCs. Hence, some macroeconomic factors (i.e., GNP, GDP, national income) can be included in future studies to examine their impacts on container shippers' performances.

It is not possible to find data about some shipping companies, such as Mediterranean Shipping Company (MSC), Evergreen Line, Mitsui O.S.K Lines (MOL), and Nippon Yusen Kabushiki Kaisha (NYK), as they do not publish their financial data and activity reports. Hence, these companies have not been included in the scope of the current study because experts do not have sufficient information on these shipping companies' financial and operational performances. In addition, this research focuses on the financial and operational performances of the CSCs only, and it does not consider the sustainability and environmental performance of these companies. However, these factors can influence the overall performance of CSCs. Therefore, these factors can be incorporated into the scope of the evaluation by authors carrying out future studies on this issue.

Although the evaluated CSC owns more than 70 % of the container shipping market, authors and researchers may consider adding some shipping companies into the scope of evaluation in future studies. Furthermore, even though the T2NFN-EATWIOS approach, which is the proposed model in this work, is a robust, reliable, and applicable performance analysis technique, authors carrying out future research and studies may try combinations between EATWIOS and different fuzzy sets such as spherical, picture, intuitionistic, q-Rung Orthopair, and Pythagorean fuzzy sets. Eventually, a user-oriented software can be utilized to possess the modules with less computational complexity.

6. Conclusion

Developing new decision-making approaches can help to overcome existing drawbacks, constructional problems, and deficiencies of the decision-making techniques previously presented by various authors. Therefore, each reasonable and logical suggestion adds advantages and value to the literature. In addition, it can be accepted as continuous improvement and development by the Multi-Criteria Decision-Making (MCDM) community. It also helps practitioners in various fields to make rational, logical, and reasonable decisions. Thus, making appropriate decisions can contribute to increasing the sustainability, productivity and effectiveness of the industries and institutions.

This study tried to present a novel efficiency analysis approach that can deal with highly complicated uncertainties aside from its many valuable advantages and contributions. A new algorithm was offered to evaluate the organizations' performance, i.e., companies, institutions, and so on. Following the proposed algorithm of the model, the criteria weights were calculated without requiring additional weighting techniques. After the normalized criteria values were computed, distance measures of each input and output factor were identified, and these values helped to calculate the overall efficiency of each option. A real-life selection problem faced by a large-scale Turkish freight forwarder company concerning the selection of a CSC as a strategic partner was handled to analyze the overall efficiency of the proposed T2NFN approach. After implementing the developed model, a comprehensive sensitivity analysis with three phases was performed to examine the validity and robustness of the model. The results of the sensitivity analysis revealed the consistency, stability, and robustness of the T2NFN-EATWIOS model because significant and severe changes have not been found in the ranking performance and productivity scores of the alternatives even with excessive modifications. Although the classical version of the algorithm is already powerful and practical and provides more realistic and efficient results in comparison with the other efficiency analysis approaches, it cannot apprehend and process the existing ambiguities; hence, this can be accepted as a great disadvantage of the technique. This work proposed to extend the EATWIOS approach with the help of the T2NFN set to improve and strengthen the EATWIOS technique, as the T2NFN set can capture both predictable and unpredictable uncertainties. When the advantages of the novel T2NFN-EATWIOS model are considered, the proposed model can provide a robust, flexible, and powerful performance analysis tool to practitioners in various industries.

CRediT authorship contribution statement

Sarfaraz Hashemkhani Zolfani: Writing – original draft, Conceptualization, Methodology, Validation, Software. **Ömer Faruk Görçün:** Writing – review & editing, Conceptualization, Methodology, Data curation, Visualization, Investigation. **Mustafa Çanakçıoğlu:** Writing – review & editing, Data curation, Validation. **Erfan Babaee Tirkolaee:** Writing – review & editing, Investigation, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. The preliminary information about T2NNs

Definition 1. (Abdel-Basset et al., 2019): *X is a limited universe of discourse and* $F[0,1]$ *is a collection of all triangular NNs. The T2NNs set of NN is denoted as*:

$$NN = (x, T_{NN}(x), I_{NN}(x), F_{NN}(x) | x \in X) \tag{A1}$$

where $T_{NN}(x)$ defines the truth degree, $I_{NN}(x)$ denotes the indeterminacy degree, and $F_{NN}(x)$ is the degree of falsity.

Here, the 2nd abstraction level by taking into account the grades as T2NNS and thus, $T_{NN}(x) = (T_{NN(T)}(x), I_{NN(T)}(x), F_{NN(T)}(x))$; $I_{NN}(x) = (T_{NN(I)}(x), I_{NN(I)}(x), F_{NN(I)}(x))$; and $F_{NN}(x) = (T_{NN(F)}(x), I_{NN(F)}(x), F_{NN(F)}(x))$. The unit interval involves all these grades.

Remark 1: For convenience, $NN_i = (T_i, I_i, F_i)$ is named the T2NN and collection of such numbers for T2NNs.

Definition 2. (Abdel-Basset et al., 2019): *Let* NN_1 *and* NN_2 *be as before. Some operations with T2NN are defined as*:

(1) Addition “⊕”

$$\begin{aligned} NN_1 \oplus NN_2 = {} & (((T_{1(T)} + T_{2(T)} - T_{1(T)}.T_{2(T)}), (T_{1(I)} + T_{2(I)} - T_{1(I)}.T_{2(I)}), (T_{1(F)} + T_{2(F)} \\ & - T_{1(F)}.T_{2(F)})), (I_{1(T)}.I_{2(T)}, I_{1(I)}.I_{2(I)}, I_{1(F)}.I_{2(F)}), (F_{1(T)}.F_{2(T)}, F_{1(I)}.F_{2(I)}, F_{1(F)}.F_{2(F)})). \end{aligned} \tag{A2}$$

(2) Multiplication “⊗”

$$\begin{aligned} NN_1 \otimes NN_2 = {} & \Big((T_{1(T)}.T_{2(T)}, T_{1(I)}.T_{2(I)}, T_{1(F)}.T_{2(F)}), \Big((I_{1(T)} + I_{2(T)} - I_{1(T)}.I_{2(T)}), \Big(I_{1(I)} + I_{2(I)} - I_{1(I)}.I_{2(I)}\Big), \Big(I_{1(F)} + I_{2(F)} - I_{1(F)}.I_{2(F)}\Big)\Big), \Big((F_{1(T)} + F_{2(T)} \\ & - F_{1(T)}.F_{2(T)}), \Big(F_{1(I)} + F_{2(I)} - F_{1(I)}.F_{2(I)}\Big), \Big(F_{1(F)} + F_{2(F)} - F_{1(F)}.F_{2(F)}\Big)\Big)\Big). \end{aligned} \tag{A3}$$

(3) Scalar multiplication, where $\boldsymbol{\lambda > 0}$

$$\lambda NN_1 = \Big(\Big(\Big(1 - (1 - T_{1(T)})^{\lambda}\Big), \Big(1 - (1 - T_{1(I)})^{\lambda}\Big), \Big(1 - (1 - T_{1(F)})^{\lambda}\Big)\Big), (I^{\lambda}_{1(T)}, I^{\lambda}_{1(I)}, I^{\lambda}_{1(F)}), (F^{\lambda}_{1(T)}, F^{\lambda}_{1(I)}, F^{\lambda}_{1(F)})\Big). \tag{A4}$$

(4) Power, where $\boldsymbol{\lambda > 0}$

$$NN_1^{\lambda} = \Big(((T^{\lambda}_{1(T)}, T^{\lambda}_{1(I)}, T^{\lambda}_{1(F)})), \Big(\Big(1 - (1 - I_{1(T)})^{\lambda}\Big), \Big(1 - (1 - I_{1(I)})^{\lambda}\Big), \Big(1 - (1 - I_{1(F)})^{\lambda}\Big)\Big), \Big(\Big(1 - (1 - F_{1(T)})^{\lambda}\Big), \Big(1 - (1 - F_{1(I)})^{\lambda}\Big), \Big(1 - (1 - F_{1(F)})^{\lambda}\Big)\Big)\Big). \tag{A5}$$

Definition 3. (Abdel-Basset et al., 2019): NN_1 *is as before. Measures of score and accuracy can be computed as*:

$$S(NN_1) = \frac{1}{12}\left(8 + (T_{1(T)} + 2T_{1(I)} + T_{1(F)}) - (I_{1(T)} + 2I_{1(I)} + I_{1(F)}) - (F_{1(T)} + 2F_{1(I)} + F_{1(F)})\right), \tag{A6}$$

$$A(NN_1) = \frac{1}{4}((T_{1(T)} + 2T_{1(I)} + T_{1(F)}) - (F_{1(T)} + 2F_{1(I)} + F_{1(F)})), \tag{A7}$$

where $S(NN_1)$ and $A(NN_1)$ are score and accuracy measures. These measures are useful to find the superior alternative. In other words, the convergent classification values of each alternative are ordered with the help of score and accuracy values.

It should be noted that if $S(NN_1)\rangle S(NN_2)$, then $NN_1 > NN_2$ which means that NN_1 is superior to NN_2. If $S(NN_1) = S(NN_2)$ and $A(NN_1)\rangle A(NN_2)$, then $NN_1 > NN_2$ which shows that NN_1 is superior to NN_2. Finally, if $S(NN_1) = S(NN_2)$ and $A(NN_1) = A(NN_2)$, then $NN_1 > NN_2$, denoting that there is no difference between NN_1 and NN_2.

Appendix B. Supplementary tables

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