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Container vessel selection for maritime shipping companies by using an extended version of the Grey Relation Analysis (GRA) with the help of Type-2 neutrosophic fuzzy sets (T2NFN)

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ABSTRACT

Contrary to expectations, based on occurring changes in customer behaviours related to consuming and shopping triggered by the pandemic, the global container shipping market has continued to grow during COVID 19. Experts estimate that these increases will continue in the future due to changing consumption habits. However, container shipping companies (CSCs) may soon encounter many troubles and challenging situations. They have an extremely fragile structure and may be entirely unprotected when they encounter unexpected situations sourced from external factors. (i.e., due to grounding of a ship, complete blockage of the Suez channel for three weeks can be given as a clear example of that). Hence, selecting an appropriate container vessel type can help construct a healthier container shipping system less influenced by adverse conditions for decision-makers and practitioners. Besides, it can provide a more effective and productive maritime transportation environment for all stakeholders. However, selecting a proper container vessel type is a complicated decision-making problem since many conflicting criteria and complex ambiguities exist. The current paper proposes an extended version of the GRA technique with the help of type-2 neutrosophic fuzzy sets (T2NFN) for capturing and processing uncertainties better than the traditional MCDM frameworks. According to the obtained results, C6, container carrying capacity, is the most influential criterion and the type of post-Suezmax container vessel is the best option for the CSCs, as it provides advantages at a satisfactory level for almost all criteria than others. After the proposed model was applied, a comprehensive sensitivity analysis (SA) was performed to test the validity of the T2NFN GRA approach. The results of SA approve the applicability, effectivity, and robustness of the model.

1. Introduction

Container shipping is an Influential element of global trade and is the essential component of the global supply chains (GSCs) due to many valuable advantages provided to the other partners of the GSCs. It allows for faster cargo transportation over long distances with lower transport costs. Also, there are fewer customs procedures such as inspection and control compared to the other transport modes and alternatives. Also, it provides operational speed at an incomparable level to other traditional maritime transport alternatives since handling operations can be performed more efficiently and speedy.

Briefly, container freight transport is one of the most crucial components of the global transport chain and global material flow. It is a cost-effective, flexible, and integrable transport system. Depending on these relative advantages, container shipping has increased its share in international transportation in recent years increasingly. As a result, container shipping has shown rapid development worldwide from 1995 to 2018, and the market share of container freight transportation has regularly ever-increasing each passing year (UNCTAD, 2021). Container freight transportation grew an average of 4.7% annually in the last two decades. UNCTAD estimated that decreases in cargo volume transported by container transportation systems would occur during 2020

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depending on the global pandemic COVID-19 (UNCTAD, 2019). Contrary to these expectations, based on happening changes in customer behaviours related to consuming and shopping triggered by the pandemic, the global container shipping market has continued to grow during the COVID 19.

Although the container freight transport system is growing worldwide, some structural problems need to be solved. Initially, idle capacity in container freight transport was an average of 5.7%, and approximately 1.3 million TEU is not used in the market (Shipping Watch, 2021). In the last year, 352 container ships were unemployed. According to the annual report published by Alphaliner, One-third of the idle capacity is made up of container vessels of 7,700 to 19.000 TEUS (Alphaliner, 2021). It proves that container shipping companies might make mistakes in ship evaluation and selection processes, as a significant part of their vessel fleet can stay idle despite high and ever-increasing demands. It can be accepted as a managerial failure and weakness of these companies because of the administrative liability of container shipping companies and some structural problems existing in decision-making processes. The larger container ships stay insufficient concerning meeting the unit transport costs, and container freight shipping companies face some difficulties operating these vessels.

In addition, the container shipping industry has encountered many challenging situations and problems due to increased global competitive pressure. First, they must continuously find more optimal and effective solutions than previous operations to carry out effective and productive transport operations. Furthermore, expectations of their customers on more quality transport services with lower costs have been ever-increasing continuously. Hence, constructing a well-designed and well-operated transport chain and the system is crucial for practitioners to provide more flexible and effective container shipping services to container shipping companies. The most Influential phase of constructing the container shipping system for container shipping companies is to generate an effective and productive container vessel fleet by selecting appropriate vessels. However, choosing proper container vessel types is not easy for decision-makers because many conflicting criteria affect the evaluation processes. Also, decision-makers responsible for determining suitable container vessels may have to decide with a lack of data and insufficient information due to highly complicated uncertainties in assessment processes carried out for determining container vessels. Existing conflicting criteria and complex uncertainties make it difficult to decide for decision-makers in the field of the maritime industry. Moreover, there are also many alternatives related to container vessels for practitioners. Thus, selecting an appropriate container ship type alternative is exceptionally difficult and time-consuming for decision-makers.

The current paper aims to present a robust, practical, and powerful decision-making frame that can overcome many complicated uncertainties to solve decision-making problems encountered in the maritime industry. For this purpose, the current paper proposes the extended version of the Grey Relation Analysis (GRA) approach based on Type-2 neutrosophic fuzzy sets (T2NFN) due to many advantages presented in the following sections.

The main aim of this integration is to provide an opportunity for the experts to express the evaluations better by using Type-2 neutrosophic numbers (T2NFNs) and modeling these evaluations more objectively and practical. Also, it aims to contribute to the literature by presenting a novel evaluation tool for solving the container vessel selection problem in the maritime industry. According to the authors ’ information, the proposed approach has been applied for the first time to handle the container vessel selection problem. In addition, the main contributions of the current paper can be summarized as follows.

In addition, the main contributions of the current paper can be summarized as follows.

i) It presents the criterion set identified by performing a comprehensive literature review and fieldwork carried out together with experts. The criterion set is entirely updated and suitable for the real-life decision-making problems encountered in the maritime industry. ii) It presents a novel Delphi approach based on T2NFN to categorize the criteria and identify the influential criteria affecting container vessel selection. iii) The GRA approach based on T2NFNs can identify the criteria weights without requiring an additional weighting technique. iv) It uses T2NFNs to capture and process many complicated ambiguities existing in an evaluation process for selecting appropriate container vessels and contributes to rational and logical decision-making. v) It overcomes many uncertainties related to differences among the experts' opinions in providing complete consensus among the experts' evaluations.

The rest of this paper is organized as follows. The following section presents a literature review of marine vessel selection in the maritime industry. In section 3, the proposed T2NFN-GRA technique and its basic algorithm are explained in detail. In section 4, the proposed model was applied to solve the decision-making problem on the container vessel selection encountered in the field of the maritime industry to demonstrate the implementation of the proposed T2NFN approach. Also, we performed a comprehensive sensitivity analysis consisting of four phases to test the validity, robustness, and applicability of the proposed MCDM framework. In section 5, the obtained findings and overall results are summarized and discussed. In section 6, the study is concluded, and the set of limitations is identified. Next, recommendations for authors who carry out research on this issue in the future are indicated.

Table 1
The previous studies existing in the related literature.

The previous papers for solving marine vessel selection		
Authors	Vessel Types	Approaches
Şener (Sener, 2016)	Cargo Carriers	The DEMATEL
Şener & Öztürk (Sener and Ozturk, 2015)	Bulk Carrier	Quality function deployment (QFD)
Kovačić & Mrvica (Kovacic and Mrvica, 2017)	Cruise Ships	PROMETHEE and GAIA
Yang et al. (Yang et al., 2011)	Oil Tanker	Approximate TOPSIS
Wibowo & Deng (Wibowo and Deng, 2012)	Not clear	The Fuzzy Multi-Attribute Utility Theory (MAUT)
Yang et al. (Yang et al., 2018)	Oil Tanker	Dempster-Shafer and Evidential Reasoning Approach
Cedolin & Sener (Cedolin and Sener, 2016)	Not clear	Fuzzy goal programming
Xie et al. (Xie et al., 2008)	VLCC tankers	ER (Evidential reasoning) Approach
The previous papers using the fuzzy GRA, IF GRA and T2NFN GRA approaches		
Authors	Subject	Approaches
Surekha et al. (2021) (2021)	Powder mixed EDM	Fuzzy GRA
He et al. (2022) (2022)	Heat pipe-cooling battery thermal	Fuzzy GRA
Chen & Ren (2018) (2018)	Alternative aviation fuels	Fuzzy ANP & GRA
Zuo et al. (2016) (2016)	The micro-cylindrical combustor	Fuzzy GRA
Zhu et al. (2018) (2018)	Blast furnace hearth	Fuzzy GRA
Luo et al. (2015) (2015)	Maintainability indices	Fuzzy GRA-GRA
Pramanik & Mondal (2015)(2015)	Legal guardian for schools	Interval Neutrosophic GRA
Liu & Yang (2019) (2019)	Expanding production scale	Single-Valued Neutrosophic-GRA
Pramanik & Mallick (2020) (2020)	Theory explanation	SVTrapezoidal Neutrosophic GRA
Rani et al. (2021) (2021)	Telecom service providers	Intuitionistic fuzzy GRA

2. Literature review

In the current paper, the authors' performed a comprehensive literature review. For this purpose, central scientific databases such as Web of Science (WoS), SCOPUS, Google Scholar, and ISI were reviewed using

Table 2
The selection criteria used in the previous works.

Code	Criteria	Authors							
		Şener (2016)	Şener & Öztürk (2015)	Kovačić & Mrvica (2017)	(Yang et al., 2011)	(Wibowo and Deng, 2012)	(Yang et al., 2018)	(Cedolin and Sener, 2016)	(Xie et al., 2008)
C1	Cost	✔	✔	✔			✔	✔	
C2	Payment due date	✔							
C3	Delivery time	✔	✔						
C4	The reputation of the shipping company	✔	✔					✔	
C5	Flag	✔							
C6	Year of construction (Age of the ship)	✔	✔		✔		✔	✔	
C7	Duration of detentions	✔	✔				✔	✔	
C8	Class	✔							✔
C9	Gross tonnage (Ship capacity)	✔				✔			
C10	Speed	✔				✔			✔
C11	Experience in the sector (Years)		✔						
C12	The general condition of the ship		✔				✔	✔	
C13	Delivery of cargo in an undamaged condition		✔						
C14	Hydrometeorological			✔					
C15	Technical- technological			✔					
C16	Socio-cultural			✔					
C17	Institutional			✔					
C18	Bottom shell plating thickness						✔		
C19	Side shell plating thickness				✔	✔	✔		
C20	Main engine reliability				✔		✔		✔
C21	Auxiliary engine reliability				✔	✔	✔		
C22	Loading pumps, valves				✔		✔		
C23	Discharging pumps, valves				✔		✔		
C24	Single skin vessel				✔		✔		
C25	Double skin vessel				✔		✔		
C26	Single bottom plating				✔		✔		
C27	Double bottom plating				✔		✔		
C28	NOx emission				✔		✔		
C29	SOx emission				✔		✔		
C30	Open sea consumption				✔		✔		
C31	Within port limit consumption				✔		✔		
C32	Store consumption				✔	✔	✔		✔
C33	Crew salary				✔	✔	✔		✔
C34	Draft of vessel				✔		✔		✔
C35	Breadth of vessel				✔		✔		✔
C36	Level of toxicity					✔			
C37	Level of radioactivity					✔			
C38	Level of flammability					✔			
C39	Size of the ship								✔
C40	The net tonnage of the ship								✔
C42	Insurance cost								
C43	Level of corrosiveness								
C44	Pollution prevention								

keywords such as maritime vessel selection, ship selection, container vessel selection, and MCDM. We tried all combinations of these keywords to find all previous works related to the existing literature directly or indirectly. When we performed a literature review, we noticed severe and surprising gaps in the literature. First, the number of studies is exceptionally scarce.

Furthermore, according to the authors' information, there is no paper dealing with container vessel selection. Available papers focused on vessel types such as tankers, dry bulk carriers, and cruise ships. The second gap is related to the implemented MCDM techniques by previous works. The authors performing works in the literature mostly preferred to use traditional and classical MCDM approaches. The previous papers preferred MCDM techniques and focused vessel types are presented in Table 1.

As seen in Table 1, although it is possible to find a limited number of papers using the extended version of the GRA technique based on various sets such as Interval Neutrosophic, Single-Valued Neutrosophic, Single-Valued Trapezoidal Neutrosophic, Intuitionistic fuzzy sets, in the literature. There is no paper using an extended version of the GRA approach with the help of the T2NFN sets, despite the many valuable advantages of the T2NFN sets. In addition, many works use the GRA technique based on the classical fuzzy sets in the literature, and we decided to summarize these works in Table 1.

The DEMATEL technique has some disadvantages. The basic algorithm of the DEMATEL approach is very complicated because it requires too many comparisons among criteria. Hence, decision-makers may have to eliminate some factors to make the assessment processes easier. It can cause many deteriorations and deviations in the final results, and the reliability of the results can be affected by these deviations. More importantly, it cannot be applicable when uncertainties exist in an assessment process because the classical DEMATEL technique requires actual values derived from the evaluations of decision-makers, and ambiguities can reduce the reliability level of the approach on a vast scale. Besides, it cannot consider the aspiration level of factors or obtain partial ranking orders of criteria (Si et al., 2018). Also, the DEMATEL technique cannot demonstrate the absolute degree of relations between the selection criteria (Aghelie et al., 2016). Similar structural problems and drawbacks can be indicated for QFD (Bizfluent. Limitations of QFD, 2021; Abu-Assab, 2012; Wolniak, 2018).

In addition, the PROMETHEE may not produce appropriate solutions if decision-makers cannot express their preference between 0 and 1 (Keyser and Peeters, 1996). However, these two intervals may not be sufficient for expressing the DMs' preferences in real life. It may not be possible to identify a ratio scale for attributes in many situations. Also, it requires criteria weights identified with a realistic approach and suitable for real-life decision-making problems. Therefore, it is sensitive to the criteria weights at a maximal level, and any change can cause dramatic changes in the ranking results. Because of that, the PROMETHEE technique cannot provide a reliable MCDM framework to solve decision-making problems in the selection of container vessels. In addition, it cannot overcome uncertainties and complicated situations, and it may remain unsolved in the face of these kinds of problems. However, there are many uncertainties in decision-making problems encountered in the field of the maritime industry. TOPSIS technique suffers from rank reversal problems. It means any changes in criteria and alternatives can cause significant changes in the ranking results. Therefore, it can be accepted as a crucial problem reducing the reliability of the technique. Although approximate TOPSIS is an extended version of the classical TOPSIS approach, and it can better deal with ambiguities than the conventional version of the TOPSIS, it cannot provide a powerful and robust framework due to the rank reversal problem.

The Dempster-Shafer (D-S) deals with each piece of evidence separately and assumes that each evidence is independent (Taroun and Yang, 2011). It requires too many computations (Liu et al., 2013) and has a very complicated basic algorithm. Besides, rules should be identified consummately and outstandingly at the beginning of the process; in contrast, the final results obtained using the D-S approach may be unreliable for decision-makers. In addition, the fuzzy goal programming (FGP) approach is an efficient technique and can overcome uncertainties at a certain level. However, this technique has some drawbacks and structural problems. First, it was extended with the help of classical fuzzy set theory (TFNs), and TFNs are the version of Type-1 fuzzy sets (T1FN); hence, it cannot capture and process the ambiguities at a desirable level.

Moreover, it may not produce efficient solutions and proposes this unproductive and inefficient solution to decision-makers (Ma et al., 2017). Thus, a decision-maker may not be sure of the proposed results of the FGP approach, and if the results are entirely correct and optimum, they may stay in doubt still. The evidential reasoning (ER) approach cannot overcome complicated uncertainties and has a highly complex algorithm. In addition, it requires a large volume of information and data to make an analysis.

In addition to the drawbacks and limitations of the implemented techniques in previous works, there is no consensus on the selection criteria used for selecting appropriate marine vessels. Also, it is not sufficiently clear how these criteria were identified. Besides, some papers implementing the fuzzy approaches did not demonstrate the decision-makers' abilities, experiences, and why the authors selected them as experts. Therefore, the used criteria are not sufficiently reliable for practitioners in the maritime industry and authors who carry out works in the future. The selection criteria and factors used in the previous papers existing in the literature are presented in Table 2.

2.1. Research gaps

Although the container shipping industry is essential for all stakeholders of the global trade and the GSCs, we noted severe gaps in the existing literature. These gaps are summarized as follows. *i*) Previous works focused on different types of vessels, such as crude oil tankers (Yang et al., 2011; Yang et al., 2018; Xie et al., 2008), dry bulk carriers (Sener, 2016), and cruise ships (Kovacic and Mrvica, 2017). Also, it has been observed that some papers in the existing literature are not transparent that focus on which vessel classes (Wibowo and Deng, 2012). *ii*) There are no criteria set commonly accepted in the existing literature for evaluating the marine vessel, and authors carried out previous works in the literature using different selection criteria. Also, it is unclear whether the authors followed a methodological frame and what kind of empirical studies and fieldwork they performed when they identified the selection criteria. *iii*) Although many authors carrying out studies in the existing literature indicated many complicated situations and ambiguities in an evaluation process, the proposed models are not sufficient theoretical contributions, as they have some drawbacks, structural problems, and limitations. These drawbacks and structural problems, which cause many severe gaps in the existing literature, are thoroughly demonstrated in section 2, the literature review.

2.2. The primary motivations of the work

The container shipping industry is one of the fields most affected by many highly complicated uncertainties. These ambiguities generate for many reasons. Song (Song, 2021) indicated some of the reasons as customer demands, shipping network, vessel capacity schedule, and container shipping companies' policies that can influence the strategic and managerial decisions of the container shipping companies (i.e., container vessel selection, re-structuring, etc. sizing the fleet). Shipbuilding technologies have continued to improve, and it influences the preferences of the decision-makers in the maritime industry and makes it complicated to decide. Besides, Fan & Luo (Fan and Luo, 2013) pointed out that ship investment is one of the most complicated decisions due to uncertainties in future demand and the strategic behaviours of competitors and indicated that freight volatility in the container shipping market increases existing uncertainties. Bendall & Stent (Bendall and Stent, 2005) and Jeon (Jeon, 2022) highlighted that demand volatility is another main reason for the ambiguities in the container shipping industry. In addition, global freight charges have shown variability on a vast scale depending on increasing competition in the container shipping industry. Also, notably, bunker fuel costs and many input costs in the maritime industry are volatile. In addition, legislative regulations have been taken by International Maritime Organization (IMO) based on current developments that may cause uncertainties (Haehl and Spinler, 2020).

In addition to those, many unpredictable uncertainties due to climate conditions, force majeure, and other adverse situations can also affect the decision-making process in the container shipping industry. For instance, aside from the global pandemic emerging in 2019, quickly spreading and influencing profoundly global trade, some developments (e.g., blockage of the Suez channel due to grounding a container vessel) causing high costs have increased the uncertainties. These kinds of unpredictable ambiguities can primarily affect the strategic decisions of the companies in addition to their performance concerning productivity and sustainability. Besides, humans make these decisions, and decision-makers may hesitate concerning ship investments (Boltürk, 2021). Therefore, there is almost complete consensus in the literature concerning ship investments influenced by these highly complicated uncertainties.

Hence, when the situations, including predictable and unpredictable uncertainties in the maritime industry, are considered, it can be accepted that selecting appropriate container vessels is a highly complicated decision-making problem. It is prevalent to apply decision-making frames integrated with the fuzzy set theory in the literature to handle these kinds of highly complicated decision-making problems.

However, the classical fuzzy set theory cannot capture all ambiguities such as inconsistency, vagueness, and imprecision (Deveci et al., 2021; Radwan et al., 2016). Type-2 fuzzy sets are a more advanced tool having advantages (Karaşan and Kahraman, 2018) than type-1 fuzzy sets, as they can deal with uncertainties better than the classical versions of the fuzzy sets. Type-2 fuzzy sets can deal with linguistic ambiguities more scientifically than type-1 fuzzy sets. Also, the type-1 fuzzy set cannot handle complex decision-making problems largely influenced by uncertainties since it does not consider non-membership functions (Mapari and DrA, 2016). The neutrosophic fuzzy set can overcome these deficiencies of the classical fuzzy sets. It can handle imprecise and

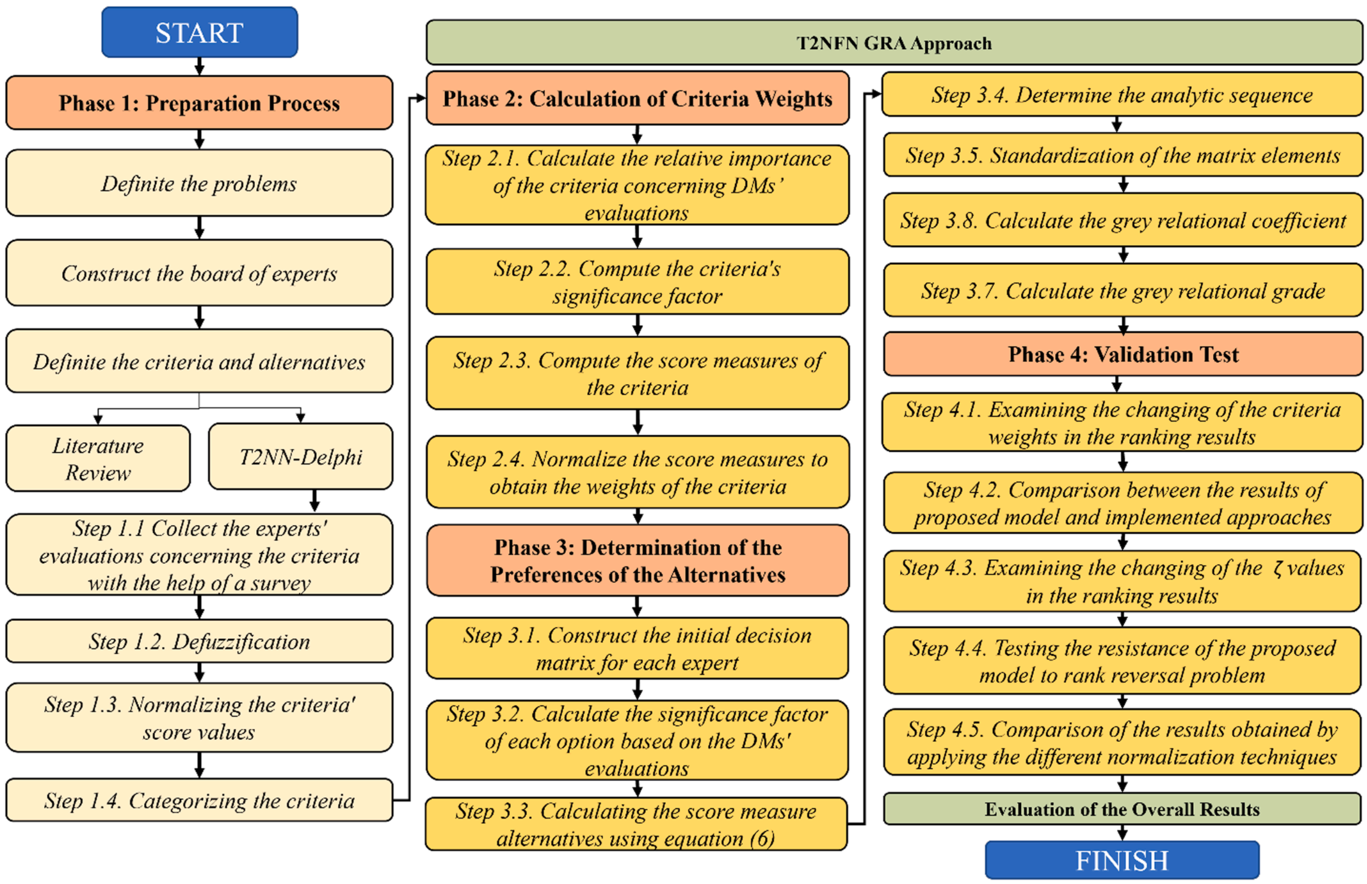


Fig. 1. The proposed T2NFN GRA approach and its basic algorithm.

inconsistent information, providinge advantages to solving complicated real-life decision-making problems (Das et al., 2020); it also considers unpredictable indeterminacies and predictable ambiguities (Nagarajan et al., 2019).

Besides, the GRA approach has been implemented to evaluate and rank the decision alternatives in the current paper. The GRA is the sub-branch of the grey system theory introduced by Deng (Ece and Şengül, 2018). This approach considers the relations between two input factors or two sub-systems to identify the similarities and differences between them (Lee and Lin, 2011; Aplak et al., 2013; ECER and GÜNAY, 2014), and these measured relations are defined as "grey relations" (Feng and Wang, 2000). Many researchers indicate that the GRA approach is a powerful and proper tool for examining complicated relations (Şahin and Karaoğlan, 2018; Aplak et al., 2013; Karaatlı, 2016) and provides to identify the preferences of the alternatives in multi-criteria decision-making processes (Kuo et al., 2008). GRA has many advantages, such as it provides the ability of advanced mathematical analysis that can handle insufficient information, lack of data, and weak knowledge (Aplak et al., 2013). This approach overcomes the deficiencies of some traditional and classical MCDM frameworks (Aruldoss, 2013). For that reason, the current study combines the advantages of the GRA approach, type-2 fuzzy sets, and neutrosophic numbers.

From this perspective, the current paper aims to fill the research gaps in the literature as mentioned in Section 2.1. It examines the evaluation processes for identifying the proper container vessel type by considering the specific characteristics and different structures of the container ships and the various and particular requirements of the container shipping companies. Also, it presents an updated and suitable criterion for the real-life decision-making problems encountered in the maritime industry. In addition, the current paper proposes to apply a novel decision-making approach based on T2NFN to solve these kinds of decision-making problems effectively, and the selection criteria and their influence degrees were identified by using the Delphi technique based on the T2NFN.

3. Research methodology

Here, we demonstrate the basic algorithm of the T2NFN GRA model consisting of four phases and 12 implementation steps. These steps and the general structure of the proposed model are given in Fig. 1. Fig. 2..

Preliminaries on neutrosophic sets.

Let us review certain fundamental concepts about T2NFNs to create a base for the integrated approach.

Definition 1. ((*Abdel-Basset et al., 2019; Deveci et al., 2021*):) *X is a limited universe of discourse and $F[0,1]$ be a collection of all triangular neutrosophic numbers. Type 2 neutrosophic number set (T2NFNS) NN is given by.*

$$NN = (x, T_{NN}(x), I_{NN}(x), F_{NN}(x)|x \in X) \tag{1}$$

Where $T_{NN}(x)$ is the degree of truth, $I_{NN}(x)$ is the degree of indeterminacy, and $F_{NN}(x)$ is the falsity degree. Here, the authors provide a second level of generalization by considering the grades as T2NFNS and hence, $T_{NN}(x) = (T_{NN(T)}(x), I_{NN(T)}(x), F_{NN(T)}(x))$; $I_{NN}(x) = (T_{NN(I)}(x), I_{NN(I)}$

$(x), F_{NN(I)}(x))$; and $F_{NN}(x) = (T_{NN(F)}(x), I_{NN(F)}(x), F_{NN(F)}(x))$. All these grades are in the unit interval.

Remark 1. *For ease of use, $NN_i = (T_i, I_i, F_i)$ is called the type 2 neutrosophic number and collection of such numbers for T2NFNS.*

Definition 2. (*(Abdel-Basset et al., 2019):*) *Let NN_1 and NN_2 be as before. Some operations with T2NFN are given by:*

(1) Addition "⊕".

$$NN_1 \oplus NN_2 = \Big(\big(\big(T_{1(T)} + T_{2(T)} - T_{1(T)}.T_{2(T)}\big), \big(T_{1(I)} + T_{2(I)} - T_{1(I)}.T_{2(I)}\big), \big(T_{1(F)} + T_{2(F)} - T_{1(F)}.T_{2(F)}\big) \big), \big(I_{1(T)}.I_{2(T)}, I_{1(I)}.I_{2(I)}, I_{1(F)}.I_{2(F)}\big), \big(F_{1(T)}.F_{2(T)}, F_{1(I)}.F_{2(I)}, F_{1(F)}.F_{2(F)}\big) \Big) \tag{2}$$

(2) Multiplication "⊗".

$$NN_1 \otimes NN_2 = \Big(\big(T_{1(T)}.T_{2(T)}, T_{1(I)}.T_{2(I)}, T_{1(F)}.T_{2(F)}\big), \big((I_{1(T)} + I_{2(T)} - I_{1(T)}.I_{2(T)}), (I_{1(I)} + I_{2(I)} - I_{1(I)}.I_{2(I)}), (I_{1(F)} + I_{2(F)} - I_{1(F)}.I_{2(F)}) \big), \big((F_{1(T)} + F_{2(T)} - F_{1(T)}.F_{2(T)}), (F_{1(I)} + F_{2(I)} - F_{1(I)}.F_{2(I)}), (F_{1(F)} + F_{2(F)} - F_{1(F)}.F_{2(F)}) \big) \Big) \tag{3}$$

(3) Scalar multiplication, where$\lambda > 0$.

$$\lambda NN_1 = \Big(\Big(\Big(1 - \big(1 - T_{1(T)}\big)^{\lambda}\Big), \Big(1 - \big(1 - T_{1(I)}\big)^{\lambda}\Big), \Big(1 - \big(1 - T_{1(F)}\big)^{\lambda}\Big) \Big), \big(I^{\lambda}_{1(T)}, I^{\lambda}_{1(I)}, I^{\lambda}_{1(F)}\big), \big(F^{\lambda}_{1(T)}, F^{\lambda}_{1(I)}, F^{\lambda}_{1(F)}\big) \Big) \tag{4}$$

(4) Power, where$\lambda > 0$.

$$NN_1^{\lambda} = \Big(\big(\big(T^{\lambda}_{1(T)}, T^{\lambda}_{1(I)}, T^{\lambda}_{1(F)}\big) \big), \Big(\Big(1 - \big(1 - I_{1(T)}\big)^{\lambda}\Big), \Big(1 - \big(1 - I_{1(I)}\big)^{\lambda}\Big), \Big(1 - \big(1 - I_{1(F)}\big)^{\lambda}\Big) \Big), \Big(\Big(1 - \big(1 - F_{1(T)}\big)^{\lambda}\Big), \Big(1 - \big(1 - F_{1(I)}\big)^{\lambda}\Big), \Big(1 - \big(1 - F_{1(F)}\big)^{\lambda}\Big) \Big) \Big) \tag{5}$$

Definition 3. (*(Abdel-Basset et al., 2019):*) *NN_1 is as before. Score and accuracy measures are given by.*

$$S(NN_1) = \frac{1}{12}\Big(8 + \big(T_{1(T)} + 2T_{1(I)} + T_{1(F)}\big) - \big(I_{1(T)} + 2I_{1(I)} + I_{1(F)}\big) - \big(F_{1(T)} + 2F_{1(I)} + F_{1(F)}\big)\Big) \tag{6}$$

$$A(NN_1) = \frac{1}{4}\big((T_{1(T)} + 2T_{1(I)} + T_{1(F)}) - (F_{1(T)} + 2F_{1(I)} + F_{1(F)})\big) \tag{7}$$

Where $S(NN_1)$ and $A(NN_1)$ are score and accuracy measures.

It must be noted that when the score of a is greater than the score of b, if T2NFN $a > b$. If score values are equal, accuracy is calculated, and if the value of a is less than b, then T2NFN $a < b$. When accuracy values are equal for both elements, we break the tie arbitrarily.

a. Identifying the criteria by using the Delphi technique based on T2NFN:

In multi-criteria decision analysis, one of the significant steps is to identify the selection criteria to structure the decision-making problem. For this purpose, it is pointed out that two different ways can be followed by Bazrafshan et al. (Bazrafshan et al., 2021): First is to determine the criteria based on the previous studies existing in the literature. The second is to identify the criteria (factors) affecting the selection process based on experts' evaluations. The current paper prefers to follow a mixed method including both approaches, as it has not been possible to identify definite and commonly accepted criteria set when a comprehensive literature review was performed. The Delphi technique introduced by Dalkey & Helmer (Dalkey and Helmer, 1963) includes an approach based on structured surveys, taking iterative feedback to provide complete consensus among experts on a subject and banded together (van Schoubroeck et al., 2019; Ocampo et al., 2018). More clearly, in implementing the Delphi technique, each expert presents self-individual opinions, and the technique allows experts to reach a common opinion in the last step of the Delphi technique. Hence, it represents an approach that deals with group information commonly considered in evaluation processes by practitioners (Hsu and Sandford, 2007; Deveci et al., 2022; Deveci et al., 2020). However, the classical Delphi technique may not sufficiently be a proper tool to overcome existing highly complicated uncertainties due to some structural problems (i.e., (1) the next step performed to identify the common opinion of the experts is entirely dependent on the previous step, (2) being insufficient times for making a health assessment, organizing meetings in wrong places, (3) being not sufficient sensitivity to fill out and re-send questionnaires on time, (4) existing some uncertainties in assessment processes) (Ocampo et al., 2018). In the existing literature, the fuzzy Delphi technique that can overcome ambiguities (Radfar et al., 2012) has been recommended by some previous studies (Ocampo et al., 2018; Xu, 2020) to use as a suitable assessment method (Ishikawa et al., 1993).

The current paper proposes a novel Delphi approach based on T2NFN by considering the main idea of the fuzzy Delphi technique (Ocampo et al., 2018) to identify the selection criteria affecting the container vessel selection. This approach includes *i)* collecting the experts' evaluations for relating to the indicators *ii)* combining the experts' evaluations by converting to the T2NFNs *iii)* categorizing the indicators by considering the threshold value, and identifying the final criteria set. Neutrosophic sets (NS) introduced by Smarandache (Smarandache, 1998) associated with a neutrosophic number characterizing the terms expressed with linguistic variables by decision-makers (i.e., expressing the experts' evaluation with three different terms such as truthiness, uncertainty, and falsity), and it provides the flexibility of rating to them

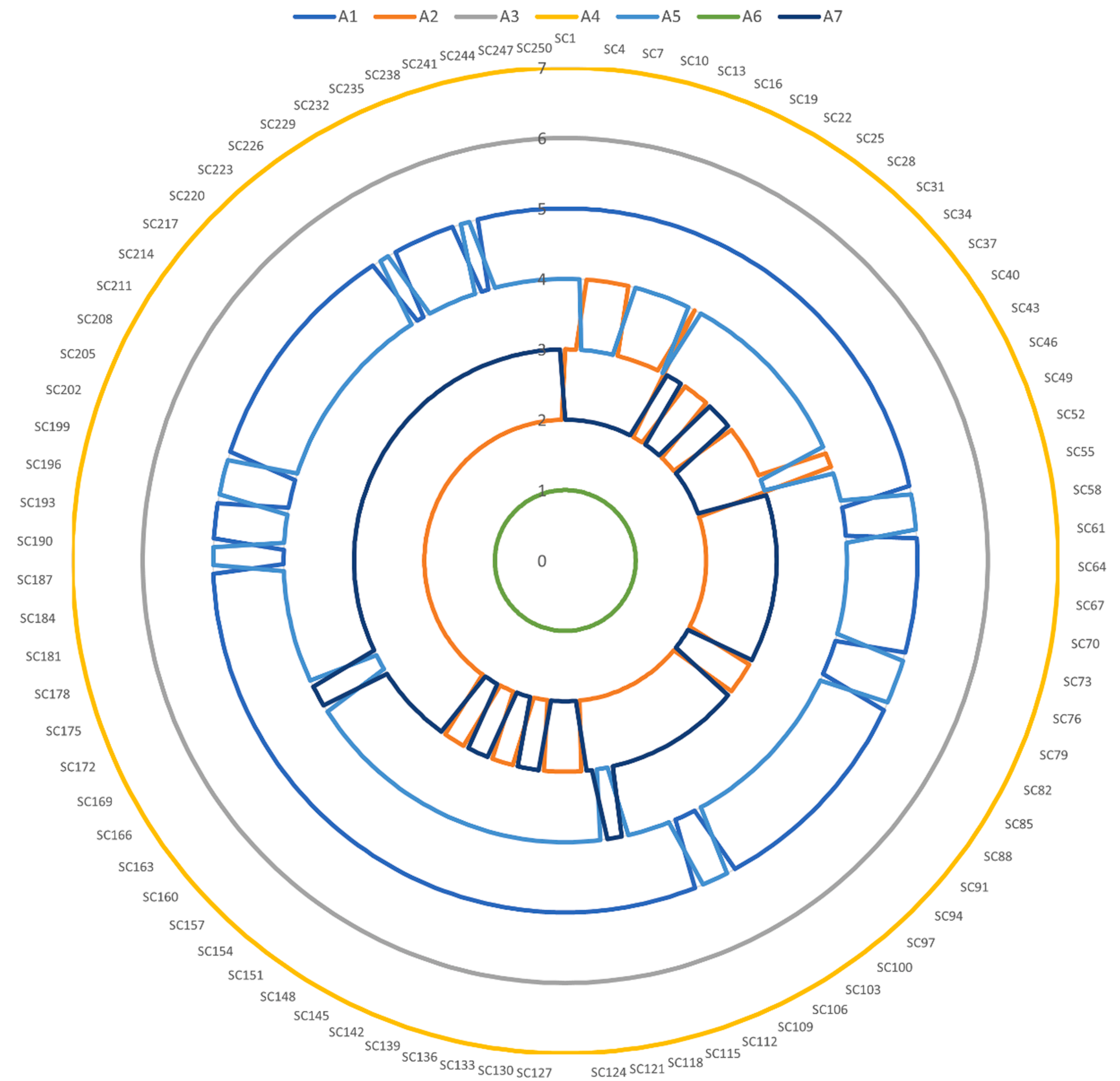


Fig. 2. The impacts of changes in criteria weights on the ranking results.

Table 3
Categories for container vessel selection criteria.

Degrees	Interval
Uninfluential	$0 \leqslant \Theta_i < 0.630$
Moderate	$0.630 \leqslant \Theta_i < 0.894$
Influential	$0.894 \leqslant \Theta_i \leqslant 1.00$

(Tiwari and Kumar, 2020). Besides, in the literature, many authors (Deveci et al., 2021; Abdel-Basset et al., 2019; Simic et al., 2021; Cali et al., 2022) pointed out that the T2NFS is a more effective tool for capturing and processing many complicated uncertainties (Deveci et al., 2021). Thus, we present an extended version of the Delphi technique based on T2NFNs by considering the classical fuzzy Delphi approach's central idea (Ishikawa et al., 1993). The implementation steps of the proposed approach are presented as follows:

Step 1.1 Collect the experts' evaluations concerning the criteria with the help of a survey: In this step, experts' opinions are taken concerning the influence degrees of the criteria by conducting a survey. The linguistic evaluations performed by experts are converted to the T2NFNs corresponding to the linguistic terms given in Table 5, and the initial T2NFN decision matrix is constructed. Then, the average value ($\overline{z}_i$) of evaluations for each i criterion $(i = 1, 2, ..., n)$ is computed using Eq. (8).

$$\overline{z}_i = \frac{1}{d}\sum_{\forall d} K_{id} \tag{8}$$

Where d denotes the number of experts and $K_{id}(i = 1, 2, ..., n)$ symbolizes the degree of ratings for i criterion performed by each expert.

Step 1.2. Defuzzification: the obtained T2NFN values are defuzzified with the help of the score function given in Eq. (6). Eq. (9) is applied to compute defuzzified values$(\overline{z}_i)$.

$$d(\overline{z}_i) = \left[\frac{\left(8 + \left(\overline{z}_i^{T_T} + 2\overline{z}_i^{T_I} + \overline{z}_i^{T_F}\right) - \left(\overline{z}_i^{I_T} + 2\overline{z}_i^{I_I} + \overline{z}_i^{I_F}\right) - \left(\overline{z}_i^{F_T} + 2\overline{z}_i^{F_I} + \overline{z}_i^{F_F}\right)\right)}{12}\right] \tag{9}$$

Where $d(\overline{z}_i)$ denotes the score values of aggregated significance value of each criterion.

Step 1.3. Normalizing the criteria' score values: Each criterion's score value is normalized using Eq. (10).

$$\Theta_i = \frac{\omega_i}{\max(\omega_i)} \tag{10}$$

Step 1.4. Categorizing the criteria: In the last step, Θ values computed in the previous step are categorized based on Table 5, and the criteria are classified into three groups presented in Table 3.

b Identifying the criteria weights.

In this stage, the criteria weights are identified by following the algorithm of the proposed model. This phase consists of four implementation steps as follows.

Step 2.1. Calculate the relative importance of the criteria concerning DMs' evaluations: In this step, criteria weight coefficients are calculated. First, e number of experts $\xi = \{\xi_1, \xi_2, ..., \xi_e\}$ evaluate the criteria $C_j=\{C_1, C_2, \ldots, C_n\}$ by considering the T2NFN linguistic scale. Hence, matrices that consist of expert evaluations are generated.

Where;$\Im = \left[\gamma_{jb}\right]_{n\times e}$, $(j = 1,..,n;\ b = 1,2,...,e)$; denotes the initial matrix for the criteria, and γ_{jb} represents the elements of the matrix; $\gamma_{jb} = \left[\left(\gamma_{jb}^{T_T}, \gamma_{jb}^{T_I}, \gamma_{jb}^{T_F}\right), \left(\gamma_{jb}^{I_T}, \gamma_{jb}^{I_I}, \gamma_{jb}^{I_F}\right), \left(\gamma_{jb}^{F_T}, \gamma_{jb}^{F_I}, \gamma_{jb}^{F_F}\right)\right]$

Step 2.2. Compute the criteria's significance factor: Next, each criterion's significance factor is identified based on the preferences of the DMs. This value is identified for each degree of the T2NFN; hence, a T2NFN is formed for each factor. The value of the significant factor is computed with the help of Eq. (11).

$$SF_j = \left[\begin{array}{c} \left(\frac{\sum_{k=1}^{e}\gamma_{kj}^{T_T} - \prod_{k=1}^{e}\gamma_{kj}^{T_T}}{e}, \frac{\sum_{k=1}^{e}\gamma_{kj}^{T_I} - \prod_{k=1}^{e}\gamma_{kj}^{T_I}}{e}, \frac{\sum_{k=1}^{e}\gamma_{kj}^{T_F} - \prod_{k=1}^{e}\gamma_{kj}^{T_F}}{e}\right), \\ \left(\frac{\prod_{k=1}^{e}\gamma_{kj}^{I_T}}{e}, \frac{\prod_{k=1}^{e}\gamma_{kj}^{I_I}}{e}, \frac{\prod_{k=1}^{e}\gamma_{kj}^{I_F}}{e}\right), \\ \left(\frac{\prod_{k=1}^{e}\gamma_{kj}^{F_T}}{e}, \frac{\prod_{k=1}^{e}\gamma_{kj}^{F_I}}{e}, \frac{\prod_{k=1}^{e}\gamma_{kj}^{F_F}}{e}\right) \end{array}\right] \tag{11}$$

e denotes the number of decision-makers and $\gamma_j = \left[\left(\gamma_j^{T_T}, \gamma_j^{T_I}, \gamma_j^{T_F}\right), \left(\gamma_j^{I_T}, \gamma_j^{I_I}, \gamma_j^{I_F}\right), \left(\gamma_j^{F_T}, \gamma_j^{F_I}, \gamma_j^{F_F}\right)\right]$ denotes the value assigned by the expert to criterion j.

Step 2.3. Compute the score measures of the criteria: Next, the score measure is computed using equation (6). Hence, a vector of order $1 \times n$ is further standardized with the help of equation (12) to obtain the criteria weights.

$$w_j = \frac{S(SF_j)}{\sum_{j=1}^{n} S(SF_j)} \tag{12}$$

Where $S(SF_j)$ represents the score measure defined using equation (6), while n denotes the number of criteria. Thus, we obtain the vector of weight coefficients of criteria $w_j = (w_1, w_2, ..., w_n)^T$ used in the next step to calculate the weighted sequence of alternatives.

Step 2.4. Normalize the score measures to obtain the weights of the criteria: Next, the final weights of the criteria are identified by considering the normalized values of the criteria.

c. Computing the performance values of alternatives.

Step 3.1. Construct the initial decision matrix for each expert $(\aleph^b)$: In this phase, decision-makers perform linguistic evaluation by considering the linguistic scale for the decision alternatives. Then, these evaluations are converted to the T2NFNs corresponding to the scale. Then, each expert is denoted the basic decision-matrix$\aleph^b = \left[\overline{\theta}_{ij}^b\right]_{m\times n}$, where$\overline{\theta}_{ij}^b = \left[\left(\overline{\theta}_{ij}^{T_T(b)}, \overline{\theta}_{ij}^{T_I(b)}, \overline{\theta}_{ij}^{T_F(b)}\right), \left(\overline{\theta}_{ij}^{I_T(b)}, \overline{\theta}_{ij}^{I_I(b)}, \overline{\theta}_{ij}^{I_F(b)}\right), \left(\overline{\theta}_{ij}^{F_T(b)}, \overline{\theta}_{ij}^{F_I(b)}, \overline{\theta}_{ij}^{F_F(b)}\right)\right]$,$1 \leqslant b \leqslant e$; $i = 1,\ldots,m;\ j = 1,\ldots n$. Each pair $\overline{\theta}_{ij}^b$ takes a value from the predefined Type 2 neutrosophic scale.

Step 3.2. Calculate the significance factor of each alternative based on the DMs' evaluations: Afterward, the relative significances of the alternatives are identified concerning decision-makers' evaluations. For this purpose, equation (13) is applied.

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

where e denotes the number of experts. Hence, the T2NFN matrix of alternatives concerning criteria is generated with the help of equation (13).

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

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

Step 3.3. Calculating the score measure alternatives using Eq (6): Thus, we get a matrix of score measures input and output factors, 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$\aleph_{ij} = \left(8 + \left(\theta_{ij}^{T_T} + 2\theta_{ij}^{T_I} + \theta_{ij}^{T_F}\right) - \left(\theta_{ij}^{I_T} + 2\theta_{ij}^{I_I} + \theta_{ij}^{I_F}\right) - \left(\theta_{ij}^{F_T} + 2\theta_{ij}^{F_I} + \theta_{ij}^{F_F}\right)\right)/12$; $i = 1,\ldots,m;\ j = 1,..,n$.

Step 3.4. Preparation of factor compatibility: After the initial decision matrix is formed in the 7th step of the proposed model, implementation steps of the Grey Relational Analysis (GRA) approach (Deng, 1989), which is a multivariate method (Meng and Na, 2009; Wu, 2002), are followed.

$$\aleph_i = (\aleph_i(1), \aleph_i(2), \aleph_i(3), ..., \aleph_i(n)) \tag{16}$$

The reference series is presented as follows (Maniya and Bhatt, 2011).

$$\aleph_{0j} = \max_i\{\aleph_{ij}\} = (\aleph_0(1), \aleph_0(2), \aleph_0(3), ..., \aleph_0(n)) \tag{17}$$

Step 3.5. Standardization of the matrix elements: In this step, by considering the characteristics of the criteria, the elements of the decision matrix are normalized by using the Jüttler's and Körth's normalization (J&K-N) technique (Zavadskas and Turskis, 2008; Zavadskas et al., 2008; Chatterjee and Chakraborty, 2014; Gardziejczyk and

Zabicki, 2017; Aytekin, 2021). According to this normalization technique, the decision matrix elements are normalized using Eq (18) by considering the characteristics of the criteria.

$$\aleph_{ij}(k) = \begin{cases} 1 - \left| \dfrac{\left(\max\limits_i \aleph^0_{ij}(k) - \aleph^0_{ij}(k) \right)}{\max\limits_i \aleph^0_{ij}(k)} \right| j \in B,\ \mathrm{i} = (1,2,3,\dots,\mathrm{m}); j = (1,2,3,\dots,n) \\ 1 - \left| \dfrac{\left(\min\limits_i \aleph^0_{ij}(k) - \aleph^0_{ij}(k) \right)}{\min\limits_i \aleph^0_{ij}(k)} \right| j \in C,\ \mathrm{i} = (1,2,3,\dots,\mathrm{m}); j = (1,2,3,\dots,n) \end{cases} \tag{18}$$

Where B denotes the benefit criteria, C symbolizes the cost criteria. $\aleph_{ij}(k)$ and is the normalized values of each alternative concerning each criterion.

Step 3.6. Calculate the grey relational coefficients: These values represent the similarity of the reference series to the alternative series. The grey relational coefficient can be calculated by applying Eq (19).

$$\varepsilon(\aleph_0(k), \aleph_i(k)) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{\mathrm{oi}}(k) + \zeta\Delta_{\max}} \tag{19}$$

After the grey relational coefficients are computed, the grey relation matrix is formed.

$$G = \begin{bmatrix} g_1(1) & g_1(2) & \dots & g_1(n) \\ g_2(1) & g_2(2) & \dots & g_2(n) \\ . & . & & \\ . & . & & \\ . & . & & \\ g_m(1) & g_m(2) & \dots & g_m(n) \end{bmatrix} \tag{20}$$

Then, each matrix element is multiplied with the criterion weight calculated for each index. For this purpose, Eq (21) is implemented.

$$P = \begin{matrix} & w_1 \ w_2 \ \dots \ w_n \\ & \begin{bmatrix} g_1(1).w_1 & g_1(2).w_2 & \dots & g_1(n)w_n \\ g_2(1)w_1 & g_2(2)w_2 & \dots & g_2(n)w_n \\ . & . & & \\ . & . & & \\ . & . & & \\ g_m(1)w_1 & g_m(2)w_2 & \dots & g_m(n)w_n \end{bmatrix} \end{matrix} \tag{21}$$

Step 3.7. Calculate the grey relational grade: Grey relational grade (GRG) denotes the preference ratings of alternatives concerning the criteria. The decision alternatives are ranked by considering the GRG value of each option in descending order. Eq (22) is used for computing the GRG values of alternatives.

$$\gamma(P) = \sum_{k=1}^{n} p_{0i}(k)W(k) \tag{22}$$

4. Analysis and discussion of experimental results

Here, we applied the T2NFN GRA technique to solve the container vessel selection problem encountered in the maritime industry. The algorithm of the proposed T2NFN model consists of four phases as summarized in Fig. 1. The followed algorithm of the model is presented in detail as follows.

a. Phase 1: Preparation Process and Description of the Problem.

In the preparation process, researchers determined the main problem of the research process: is it possible to present a practical and effective mathematical tool to the decision-makers and practitioners for selecting appropriate container vessels to create more sustainable, effective, and productive container transportation chains? Then, researchers prepared research questions to find a reasonable and realistic answer to the main problem as follows. *i)* What are the significant criteria affecting the assessment process in real life for selecting the appropriate container vessel? *ii)* Is there any mathematical tool or decision support system used for assessing the container vessel alternatives in the maritime industry? *iii)* How do decision-makers decide in an evaluation process? Do they make a decision based on their own experiences and knowledge entirely? *iv)* Is it possible to use a methodological frame for solving these kinds of decision-making problems to obtain more acceptable and reasonable results?

Marine vessel selection is a highly complicated decision-making problem. It requires that the criteria be evaluated and measured simultaneously (Yang et al., 2009). However, according to the experts who are members of the BoE in the current paper, decision-makers mainly consider their own experiences and judgments when they make a decision, and using a mathematical model is not common in the maritime industry. Nonetheless, practitioners in the maritime industry must identify each ship's parameter to select the appropriate vessels.

Table 4
Demographic information about experts replying to the invitation.

Gender	Frequency	%		Frequency	%
Women	4	36.4%	***Country***		
Men	7	63.6%	Turkey	5	45.5%
Age			Germany	1	9.1%
30–34	1	9.1%	Belgium	1	9.1%
35–39	3	27.3%	Italy	1	9.1%
40+	7	63.6%	Russia	1	9.1%
Graduate			Israel	1	9.1%
Business Management	4	36.4%	France	1	9.1%
Transport Management	2	18.2%	***Experience***		
Economics	2	18.2%	10–14 years	2	18.2%
Industrial Engineering	1	9.1%	15–19 years	5	45.5%
Maritime Transportation	2	18.2%	20–29 years	4	36.4%
Duty					
Branch Manager	1	9.1%			
Container Fleet Coordinator	1	9.1%			
Container Shipping Manager	1	9.1%			
Line Manager	1	9.1%			
Operation Manager	5	45.5%			
Managing Director	1	9.1%			
Operation & Port Manager	1	9.1%			

Table 5
The criteria list.

Code	Criteria				
C1	Deadweight	C23	Payment due date	C49	Level of radioactivity
C2	Ship Length	C24	Delivery time	C50	Level of flammability
C3	Ship's Loading Length	C25	The reputation of the shipping company	C51	Insurance cost
C4	Ship's Width	C26	Flag	C52	Level of corrosiveness
C5	Draught	C27	Year of construction (Age of the ship)	C53	Pollution prevention
C6	Container Carrying Capacity	C28	Duration of detentions		
C7	Fuel consumption	C29	Class		
C8	Scrapping Cost	C30	Experience in the sector (Years)		
C9	Transport Cost	C31	The general condition of the ship		
C10	Purchase Cost	C32	Delivery of cargo in undamaged		
C11	Annual Maintenance and Repair Cost	C33	Hydro-meteorological		
C12	Secondhand Market	C34	Technical-technological		
C13-1	CO2	C36	Institutional		
C13-2	NOx	C37	Bottom shell plating thickness		
C13-3	Sox	C38	Side shell plating thickness		
C13-4	PM	C39	Main engine reliability		
C14	Required Number of Staff	C40	Auxiliary engine reliability		
C15	Block Coefficient	C41	Loading pumps, valves		
C16	Sea Margin	C42	Discharging pumps, valves		
C17	Engine Margin	C43	Single skin vessel		
C18	Ship Speed	C44	Double skin vessel		
C19	SMRC Power	C45	Single bottom plating		
C20	Manoeuvrability	C46	Double bottom plating		
C21	The empty weight of ships	C47	Breadth of vessel		
C22	Economic Life	C48	Level of toxicity		

However, they frequently encounter many complicated uncertainties regarding vessel selection parameters (Sahin et al., 2020) due to the maritime industry's highly complex and dynamic structure. Therefore, there is strong evidence in the existing literature that fuzzy approaches are the proper decision-making tools for solving decision-making problems encountered in the maritime industry. Hence, objective and subjective traditional decision-making frames may not produce effective solutions for solving the current problem because they overlook existing uncertainties in the current industry. In addition, the vessel selection processes are not only affected by predictable uncertainties but also unpredictable ambiguities largely. Hence, the maritime industry encounters unpredictable situations and uncertainties, and practitioners should make strategic decisions (Bendall and Stent, 2005) to overcome these ambiguities. However, decision-makers need a robust, reliable, and practical decision-making frame dealing with predictable and unpredictable uncertainties. Due to their structural problems, the classical fuzzy sets may remain insufficient to handle these ambiguities. At least, they overlook unpredictable uncertainties. Consequently, T2NFN sets are suitable for solving these decision-making problems, as they can

Table 6
The linguistic evaluations performed by the experts.

Code	Criteria	Experts' evaluations (E1,E2,….,E11)
C1	Deadweight	<VH, VH, VH, VH, VH, VH, VH, H, H, M, M>
C2	Ship Length	<VH, VH, VH, VH, VH, VH, H, M, M, M, M>
C3	Ship's Loading Length	<VH, VH, VH, VH, VH, VH, VH, VH, H, M, VH>
C4	Ship's Width	<VH, VH, VH, VH, VH, VH, VH, VH, H, VH, VH>
C5	Draught	<VH, VH, VH, VH, VH, VH, VH, VH, H, H, H>
C6	Container Carrying Capacity	<VH, VH, VH, VH, VH, VH, VH, VH, VH, VH, VH>
C7	Fuel consumption	<VH, VH, VH, VH, VH, VH, M, M, M, VH, VH>
C8	Scrapping Cost	<VH, VH, VH, VH, M, VH, VH, VH, VH, VH, VH>
C9	Transport Cost	<VH, VH, VH, VH, VH, VH, VH, VH, VH, M, M>
C10	Purchase Cost	<VH, VH, VH, VH, VH, VH, VH, H, H, H, H>
C11	Annual Maintenance and Repair Cost	<VH, VH, VH, VH, VH, M, M, H, H, H, H>
C12	Secondhand Market	<VH, VH, M, M, M, M, M, M, VH, VH, VH>
C13-1	CO2	<VH, H, H, H, H, H, H, H, VH, VH, VH>
C13-2	NOx	<VH, H, H, VH, VH, VH, H, H, H, H, VH>
C13-3	Sox	<VH, H, M, VH, VH, H, H, H, VH, VH, VH>
C13-4	PM	<VH, M, M, M, VH, H, H, H, VH, VH, VH>
C14	Required Number of Staff	<VH, H, H, H, H, H, H, H, H, VH, VH>
C15	Block Coefficient	<H, H, H, H, H, H, VH, H, H, H, H>
C16	Sea Margin	<VH, M, M, M, M, M, VH, VH, VH, VH, VH>
C17	Engine Margin	<VH, M, M, H, H, M, M, VH, VH, VH, VH>
C18	Ship Speed	<VH, M, M, M, H, M, M, VH, VH, VH, VH>
C19	SMRC Power	<VH, H, VH, H, VH, VH, VH, VH, H, M, VH>
C20	Maneuverability	<VH, M, VH, H, VH, VH, VH, VH, M, M, VH>
C21	Empty weight of ships	<VH, M, M, M, M, VH, H, H, H, VH, VH>
C22	Economic Life	<VH, M, H, VH, VH, VH, M, H, M, H, H>
C23	Payment due date	<ML, L, L, L, L, L, L, L, L, L, L>
C24	Delivery time	<ML, ML, L, L, L, L, L, L, L, L, L>
C25	Reputation of the shipping company	<ML, ML, ML, L, L, L, L, L, L, L, L>
C26	Flag	<ML, ML, ML, L, L, L, M, L, L, ML, L>
C27	Year of construction (Age of the ship)	<ML, M, L, L, L, L, L, L, L, L, L>
C28	Duration of detentions	<L, L, L, L, L, L, L, ML, ML, ML, ML>
C29	Class	<L, ML, ML, ML, ML, ML, L, L, L, L, L>
C30	Experience in the sector (Years)	<L, L, M, L, L, L, L, L, L, L, L>
C31	General condition of the ship	<ML, ML, L, L, L, L, M, L, L, L, L>
C32	Delivery of cargo in undamaged	<ML, ML, ML, ML, ML, ML, L, L, L, L, L>
C33	Hydro- meteorological	<ML, ML, ML, ML, ML, ML, ML, L, L, L, L>
C34	Technical- technological	<ML, L, L, L, L, L, L, M, M, L, L>
C36	Institutional	<ML, ML, ML, ML, ML, ML, ML, ML, L, L, L>
C37	Bottom shell plating thickness	<ML, ML, ML, M, L, L, L, L, L, L, L>
C38	Side shell plating thickness	<M, M, L, L, L, L, L, L, L, L, L>
C39	Main engine reliability	<M, ML, ML, ML, ML, L, L, L, L, L, ML>
C40	Auxiliary engine reliability	<L, ML, L, L, L, ML, L, H, M, L, L>
C41	Loading pumps, valves	<L, L, L, L, H, L, ML, ML, ML, ML, ML>
C42	Discharging pumps, valves	<H, L, ML, ML, ML, ML, L, L, L, L, L>
C43	Single skin vessel	<M, L, M, M, ML, L, L, ML, L, L, L>
C44	Double skin vessel	<M, ML, ML, ML, ML, ML, ML, L, L, L, L>

(continued on next page)

Table 6 (*continued*)

Code	Criteria	Experts' evaluations (E1,E2,....,E11)
C45	Single bottom plating	<M, M, ML, L, L, L, ML, L, L, L, L>
C46	Double bottom plating	<M, ML, ML, ML, ML, ML, ML, ML, L, L, L>
C47	Breadth of vessel	<ML, ML, H, H, L, L, L, L, L, L, L>
C48	Level of toxicity	<ML, H, M, L, L, L, L, L, L, L, L>
C49	Level of radioactivity	<L, M, M, M, M, L, L, L, L, L, L>
C50	Level of flammability	<L, M, ML, ML, ML, ML, ML, ML, ML, ML, L>
C51	Insurance cost	<ML, M, H, ML, ML, ML, ML, ML, ML, ML, ML>
C52	Level of corrosiveness	<H, ML, M, L, L, L, L, ML, M, L, L>
C53	Pollution prevention	<L, L, ML, M, M, ML, L, H, L, ML, L>

capture and process predictable and unpredictable uncertainties.

Identifying the criteria:

In this section, implementation of the Delphi approach based on T2NFN is demonstrated to identify the criteria influential for the container vessel selection. First, a board of experts (BoE) consisting of 11 highly experienced professionals having extensive knowledge of the maritime industry was constructed by researchers. we identified some criteria to be a member of the BoE, such as (1) being a member of a professional association on maritime transportation. (2) graduated from the related department of a reputable university. (3) having experience in the maritime industry of at least 15 years as a senior executive or company owner. (4) Participate as decision-makers in an evaluation process for carrying out ship selection at least once. Next, we evaluated 34 candidates by considering these criteria with the company's senior executives. Finally, we selected eleven experts who are entirely compatible with the criteria by eliminating 23 candidates.

After we identified the members of the BoE, we organized many meetings and face-to-face interviews with these experts and directed the research questions to them. Also, we presented the criteria list prepared by considering the criteria sets used in the previous works to the experts and requested to examine these criteria indicated in the list from each expert. Then, we identified the criteria used in the current paper by following the basic algorithm of the T2NFN Delphi approach.

Round 1: In the first step of the T2NFN Delphi approach (Hsu and Sandford, 2007), we prepared a set of open-ended questionaries. Then, we directed these questions to the experts through e-mail after a short preliminary meeting performed with each expert. We requested each expert to prepare a list for the selection criteria and note all criteria that come to their mind. In this first round, all members of the BoE have been invited to answer this question. Details of eleven experts invited to participate in the meetings are presented in Table 4. All members of the BoE replied to this invitation in the affirmative.

Round 2. After the first round was completed, the researchers collected the lists prepared by the experts, and the repetitive criteria were eliminated. The criteria used in the previous studies have been identified by performing a comprehensive and detailed literature review (Refer to Table 2). Next, these criteria were combined with the criteria identified by the experts and a comprehensive criteria list was prepared and re-presented to the experts for evaluation. The researchers requested the experts to evaluate these criteria. Also, they requested to give information about the criteria that should be eliminated or added with the reasons. Besides, the researchers asked the experts whether they were sure about their decisions to provide complete consensus among the experts.

Round 3. The researchers evaluated the information concerning the previous round about the criteria that will be eliminated and added to the list. The criteria both build consensus and do not provide consensus were identified and re-presented to the experts. The researchers asked the experts whether they were sure about their decisions in the previous round, and eleven experts replied to this question. The researchers evaluated the given answers, and it has been observed that there is complete consensus among the experts that the criteria identified in the previous rounds should be included in the evaluation process. Therefore, the researchers decided to pass to the next round.

Round 4. A questionnaire form was prepared by considering the linguistic scale given in Table 10 to take the experts' opinions about the significance of each criterion identified in the previous rounds. The experts performed linguistic evaluations by considering the linguistic terms given in Table 10. The linguistic evaluations performed by experts are presented in Table 6.

This list, including the experts' evaluations, was re-presented to the experts and asked them again whether they were sure about these evaluations performed by them. According to replies given by these experts, they were sure about their evaluations completely. Then, the linguistic evaluations performed by the experts were converted to the T2NFNs corresponding to the linguistic scale. Next, the results obtained using Eqs (7), (8), and (9) were summarized in Table 7.

The obtained results were presented to the experts, and it has been decided to deal with the criteria in the sub-group identified as "Influential" by considering the feedback provided by the experts. Also, there is complete consensus among the experts and the researchers. Thus, the criteria categorized in the sub-group of "Influential" were identified as the selection criteria in the current study.

Comparing the fuzzy Delphi technique and the proposed approach.

In this section, the results of the proposed Delphi technique based on T2NFN as given in Table 7 have been compared with the fuzzy Delphi approach (Ishikawa et al., 1993). The evaluation scale presented in the study carried out by Zhang (Zhang, 2017) has been used to implement the fuzzy Delphi technique, and the criteria have been categorized as $0\leqslant \Theta_i < 0.60$ Uninfluential, $0.60\leqslant\Theta_i < 0.840$ Moderate, $0.840\leqslant\Theta_i\leqslant 1.00$ and Influential The results obtained by implementing the fuzzy Delphi approach are presented in Table 8.

As shown in Table 8, five criteria are classified in the sub-group of "Moderate", and 22 criteria are categorized in the sub-group of "Influential". Hence, while it is required that 28 criteria, which are classified as Uninfluential, should be excluded from the evaluation process, some of them have been categorized as "Medium" and have been included in the scope of the assessment. Besides, all criteria from C1 to C22 proposed as the criteria used in the current study by the proposed model are the suggested criteria by the fuzzy Delphi approach. Consequently, the obtained results support the results of the proposed approach.

Identification of the final criteria.

The final selection criteria and their descriptions are presented in Table 9.

The current paper focuses on the selection of newly built container vessels. Then, we identified the decision alternatives together with the board members and selected the types of container vessels such as A1ULCV, A2 New Panamax, A3 Post Panamax, A4 Panamax, A5 Suezmax, A6 Post Suezmax, and A7 Post Malacca Max as decision alternatives.

b. Phase 2: Calculation of Weights of Criteria.

In the second phase, criteria weights were identified by following the implementation steps of the proposed model.

Step 1: In this step, eleven decision-makers selected as members of the board of experts assessed the criteria (Table 9) using the T2FNN linguistic scale is presented in Table 10.

The linguistic evaluations performed by experts for determining the criteria weights are given in Table 11.

Step 2: Next, we performed a fusion of decision-makers' evaluations with the help of equation (11). Thus, we calculated the relative importance of the criteria concerning the linguistic evaluations performed by experts. Aggregated DMs' evaluations for the selection criteria and the T2NFN significance factor for criterion *j* are presented in Table 12.

Step 3–4: T2NFN weights for the selection criteria has been used to compute the score measures of the criteria. These values were computed with the help of equation (12). Then, the criteria weights were identified by performing a normalization operation. These values (i.e., normalized

Table 7
The results obtained by the proposed approach concerning container vessel selection.

Code	Criteria	Aggregated T2NFNs	Defuzzy	Norm. Value	Score	Rank	Degree
C1	Deadweight	<(0.8021,0.7723,0.8224),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9308	0.0201	0.9764	11	Influential
C2	Ship Length	<(0.7430,0.7295,0.7775),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9150	0.0198	0.9598	19	Influential
C3	Ship's Loading Length	<(0.8405,0.8050,0.8689),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9433	0.0204	0.9895	5	Influential
C4	Ship's Width	<(0.8656,0.8275,0.8892),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9508	0.0206	0.9974	2	Influential
C5	Draught	<(0.8527,0.8123,0.8611),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9449	0.0204	0.9912	4	Influential
C6	Container Carrying Capacity	<(0.8715,0.8348,0.8983),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9533	0.0206	1.0000	1	Influential
C7	Fuel consumption	<(0.7860,0.7641,0.8309),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9288	0.0201	0.9743	13	Influential
C8	Scrapping Cost	<(0.8478,0.8129,0.8837),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9464	0.0205	0.9928	3	Influential
C9	Transport Cost	<(0.8185,0.7891,0.8599),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9380	0.0203	0.9840	7	Influential
C10	Purchase Cost	<(0.8458,0.8044,0.8438),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9415	0.0204	0.9877	6	Influential
C11	Annual Maintenance and Repair Cost	<(0.7854,0.7552,0.7813),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9231	0.0200	0.9683	16	Influential
C12	Secondhand Market	<(0.6810,0.6852,0.7299),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.8984	0.0194	0.9425	25	Influential
C13-1	CO2	<(0.8239,0.7800,0.7848),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9307	0.0201	0.9763	12	Influential
C13-2	NOx	<(0.8314,0.7883,0.8054),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9344	0.0202	0.9802	9	Influential
C13-3	Sox	<(0.8174,0.7804,0.8139),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9327	0.0202	0.9784	10	Influential
C13-4	PM	<(0.7602,0.7381,0.7687),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9171	0.0198	0.9620	18	Influential
C14	Required Number of Staff	<(0.8162,0.7717,0.7637),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9269	0.0200	0.9724	14	Influential
C15	Block Coefficient	<(0.8003,0.7547,0.7203),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9192	0.0199	0.9642	17	Influential
C16	Sea Margin	<(0.7167,0.7119,0.7648),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9088	0.0196	0.9533	22	Influential
C17	Engine Margin	<(0.7342,0.7207,0.7559),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9110	0.0197	0.9556	21	Influential
C18	Ship Speed	<(0.7077,0.7030,0.7430),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9047	0.0196	0.9491	24	Influential
C19	SMRC Power	<(0.8252,0.7887,0.8335),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9363	0.0202	0.9822	8	Influential
C20	Maneuverability	<(0.7775,0.7555,0.8108),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9249	0.0200	0.9703	15	Influential
C21	Empty weight of ships	<(0.7254,0.7118,0.7340),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9069	0.0196	0.9514	23	Influential
C22	Economic Life	<(0.7515,0.7293,0.7470),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.9131	0.0197	0.9579	20	Influential
C23	Payment due date	<(0.2182,0.3000,0.2045),(0.0002,0.0014,0.0039),(0.0000,0.0031,0.0028)>	0.7506	0.0162	0.7874	55	Moderate
C24	Delivery time	<(0.2364,0.3000,0.2091),(0.0002,0.0011,0.0020),(0.0000,0.0025,0.0021)>	0.7528	0.0163	0.7897	54	Moderate
C25	Reputation of the shipping company	<(0.2545,0.3000,0.2136),(0.0001,0.0009,0.0010),(0.0000,0.0020,0.0015)>	0.7550	0.0163	0.7920	53	Moderate
C26	Flag	<(0.3000,0.3227,0.2500),(0.0001,0.0004,0.0003),(0.0000,0.0008,0.0005)>	0.7660	0.0166	0.8035	43	Moderate
C27	Year of construction (Age of the ship)	<(0.2455,0.3227,0.2364),(0.0002,0.0009,0.0027),(0.0000,0.0016,0.0013)>	0.7598	0.0164	0.7971	49	Moderate
C28	Duration of detentions	<(0.2727,0.3000,0.2182),(0.0001,0.0007,0.0005),(0.0000,0.0016,0.0011)>	0.7571	0.0164	0.7942	52	Moderate
C29	Class	<(0.2909,0.3000,0.2227),(0.0001,0.0005,0.0002),(0.0000,0.0013,0.0008)>	0.7591	0.0164	0.7963	50	Moderate
C30	Experience in the sector (Years)	<(0.2273,0.3227,0.2318),(0.0002,0.0012,0.0054),(0.0000,0.0020,0.0018)>	0.7576	0.0164	0.7947	51	Moderate
C31	General condition of the ship	<(0.2636,0.3227,0.2409),(0.0001,0.0007,0.0013),(0.0000,0.0013,0.0010)>	0.7620	0.0165	0.7993	47	Moderate
C32	Delivery of cargo in undamaged	<(0.3091,0.3000,0.2273),(0.0001,0.0004,0.0001),(0.0000,0.0010,0.0006)>	0.7611	0.0165	0.7984	48	Moderate
C33	Hydro- meteorological	<(0.3273,0.3000,0.2318),(0.0000,0.0003,0.0001),(0.0000,0.0008,0.0004)>	0.7630	0.0165	0.8004	46	Moderate

(continued on next page)

Table 7 (*continued*)

Code	Criteria	Aggregated T2NFNs	Defuzzy	Norm. Value	Score	Rank	Degree
C34	Technical- technological	<(0.2727,0.3455,0.2682),(0.0001,0.0006,0.0018),(0.0000,0.0009,0.0006)>	0.7689	0.0166	0.8065	40	Moderate
C36	Institutional	<(0.3455,0.3000,0.2364),(0.0000,0.0003,0.0000),(0.0000,0.0006,0.0003)>	0.7650	0.0165	0.8025	44	Moderate
C37	Bottom shell plating thickness	<(0.2818,0.3227,0.2455),(0.0001,0.0006,0.0007),(0.0000,0.0010,0.0007)>	0.7640	0.0165	0.8014	45	Moderate
C38	Side shell plating thickness	<(0.2545,0.3455,0.2636),(0.0001,0.0007,0.0037),(0.0000,0.0011,0.0008)>	0.7667	0.0166	0.8043	42	Moderate
C39	Main engine reliability	<(0.3182,0.3227,0.2545),(0.0001,0.0003,0.0002),(0.0000,0.0007,0.0004)>	0.7680	0.0166	0.8056	41	Moderate
C40	Auxiliary engine reliability	<(0.3182,0.3636,0.2864),(0.0000,0.0002,0.0005),(0.0000,0.0002,0.0003)>	0.7775	0.0168	0.8156	32	Moderate
C41	Loading pumps, valves	<(0.3455,0.3409,0.2682),(0.0000,0.0001,0.0001),(0.0000,0.0002,0.0002)>	0.7745	0.0167	0.8125	34	Moderate
C42	Discharging pumps, valves	<(0.3273,0.3409,0.2636),(0.0000,0.0001,0.0002),(0.0000,0.0002,0.0003)>	0.7726	0.0167	0.8105	36	Moderate
C43	Single skin vessel	<(0.3182,0.3682,0.3045),(0.0001,0.0003,0.0006),(0.0000,0.0004,0.0002)>	0.7797	0.0169	0.8180	31	Moderate
C44	Double skin vessel	<(0.3364,0.3227,0.2591),(0.0000,0.0003,0.0001),(0.0000,0.0005,0.0003)>	0.7699	0.0166	0.8076	39	Moderate
C45	Single bottom plating	<(0.2909,0.3455,0.2727),(0.0001,0.0005,0.0009),(0.0000,0.0007,0.0004)>	0.7709	0.0167	0.8087	38	Moderate
C46	Double bottom plating	<(0.3545,0.3227,0.2636),(0.0000,0.0002,0.0000),(0.0000,0.0004,0.0002)>	0.7718	0.0167	0.8097	37	Moderate
C47	Breadth of vessel	<(0.3455,0.3818,0.3000),(0.0000,0.0001,0.0003),(0.0000,0.0000,0.0001)>	0.7840	0.0169	0.8225	30	Moderate
C48	Level of toxicity	<(0.3000,0.3636,0.2818),(0.0001,0.0002,0.0010),(0.0000,0.0002,0.0004)>	0.7756	0.0168	0.8136	33	Moderate
C49	Level of radioactivity	<(0.3091,0.3909,0.3273),(0.0001,0.0003,0.0017),(0.0000,0.0003,0.0002)>	0.7846	0.0170	0.8230	29	Moderate
C50	Level of flammability	<(0.3727,0.3227,0.2682),(0.0000,0.0002,0.0000),(0.0000,0.0003,0.0001)>	0.7738	0.0167	0.8117	35	Moderate
C51	Insurance cost	<(0.4454,0.3636,0.3182),(0.0000,0.0000,0.0000),(0.0000,0.0000,0.0000)>	0.7909	0.0171	0.8297	26	Moderate
C52	Level of corrosiveness	<(0.3455,0.3864,0.3182),(0.0000,0.0001,0.0003),(0.0000,0.0001,0.0001)>	0.7863	0.0170	0.8248	28	Moderate
C53	Pollution prevention	<(0.3636,0.3864,0.3227),(0.0000,0.0001,0.0002),(0.0000,0.0001,0.0001)>	0.7882	0.0170	0.8268	27	Moderate

and score values) and ranking are also presented in Table 12.

For instance, the T2NFN significance factor for the C1 criterion was computed as follows.

$$
= \begin{cases}
SF_{C1}^{T_T} = \{(0.90 + 0.90 + 0.20 + \dots + 0.90) - (0.90 \cdot 0.90 \cdot 0.20 \cdot \dots \cdot 0.90)\}/11 = 0.6634; \\
SF_{C1}^{T_I} = \{(0.85 + 0.85 + 0.30 + \dots + 0.85) - (0.85 \cdot 0.85 \cdot 0.30 \cdot \dots \cdot 0.85)\}/11 = 0.6677; \\
SF_{C1}^{T_F} = \{(0.95 + 0.95 + 0.20 + \dots + 0.95) - (0.95 \cdot 0.95 \cdot 0.20 \cdot \dots \cdot 0.95)\}/11 = 0.7041; \\
SF_{C1}^{I_T} = \{(0.10 \cdot 0.10 \cdot 0.60 \cdot \dots \cdot 0.10)\}/11 = 0.0000; \\
SF_{C1}^{I_I} = \{(0.15 \cdot 0.15 \cdot 0.70 \cdot \dots \cdot 0.15)\}/11 = 0.0000; \\
SF_{C1}^{I_F} = \{(0.10 \cdot 0.10 \cdot 0.80 \cdot \dots \cdot 0.10)\}/11 = 0.0000; \\
SF_{C1}^{F_T} = \{(0.05 \cdot 0.05 \cdot 0.45 \cdot \dots \cdot 0.05)\}/11 = 0.0000; \\
SF_{C1}^{F_I} = \{(0.05 \cdot 0.05 \cdot 0.75 \cdot \dots \cdot 0.05)\}/11 = 0.0000; \\
SF_{C1}^{F_F} = \{(0.10 \cdot 0.10 \cdot 0.75 \cdot \dots \cdot 0.10)\}/11 = 0.0000;
\end{cases}
$$

$$
= [(0.6434, 0.6677, 0.7041), (0.0000, 0.0000, 0.0000), (0.0000, 0.0000, 0.0000)]
$$

The following section presents the calculation of the score measure of

Table 8
The results obtained by applying the fuzzy Delphi technique.

Code	Criteria	Aggregated TFNs			Defuzzy	Normalized value	Rank	Degree
C1	Deadweight	3,00	7,73	9,00	6,576	0,865	14	Influential
C2	Ship Length	5,00	8,45	9,00	7,485	0,984	3	Influential
C3	Ship's Loading Length	3,00	7,73	9,00	6,576	0,865	14	Influential
C4	Ship's Width	3,00	7,91	9,00	6,636	0,873	11	Influential
C5	Draught	3,00	7,55	9,00	6,515	0,857	17	Influential
C6	Container Carrying Capacity	5,00	8,82	9,00	7,606	1,000	1	Influential
C7	Fuel consumption	5,00	8,45	9,00	7,485	0,984	3	Influential
C8	Scrapping Cost	5,00	7,73	9,00	7,242	0,952	7	Influential
C9	Transport Cost	3,00	7,91	9,00	6,636	0,873	11	Influential
C10	Purchase Cost	5,00	8,27	9,00	7,424	0,976	5	Influential
C11	Annual Maintenance and Repair Cost	5,00	8,64	9,00	7,545	0,992	2	Influential
C12	Secondhand Market	3,00	7,73	9,00	6,576	0,865	14	Influential
C13-1	CO2	3,00	7,36	9,00	6,455	0,849	19	Influential
C13-2	NOx	3,00	7,36	9,00	6,455	0,849	19	Influential
C13-3	Sox	3,00	7,18	9,00	6,394	0,841	21	Influential
C13-4	PM	3,00	6,82	9,00	6,273	0,825	24	Moderate
C14	Required Number of Staff	3,00	7,00	9,00	6,333	0,833	23	Moderate
C15	Block Coefficient	5,00	7,55	9,00	7,182	0,944	8	Influential
C16	Sea Margin	5,00	8,27	9,00	7,424	0,976	5	Influential
C17	Engine Margin	3,00	8,27	9,00	6,758	0,888	10	Influential
C18	Ship Speed	3,00	7,55	9,00	6,515	0,857	17	Influential
C19	SMRC Power	3,00	7,91	9,00	6,636	0,873	11	Influential
C20	Maneuverability	3,00	7,18	9,00	6,394	0,841	21	Influential
C21	Empty weight of ships	3,00	6,82	9,00	6,273	0,825	24	Moderate
C22	Economic Life	3,00	8,64	9,00	6,879	0,904	9	Influential
C23	Payment due date	1,00	2,45	7,00	3,485	0,458	31	Uninfluential
C24	Delivery time	1,00	2,27	7,00	3,424	0,450	33	Uninfluential
C25	Reputation of the shipping company	1,00	1,36	5,00	2,455	0,323	39	Uninfluential
C26	Flag	1,00	1,36	5,00	2,455	0,323	39	Uninfluential
C27	Year of construction (Age of the ship)	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C28	Duration of detentions	1,00	1,55	5,00	2,515	0,331	38	Uninfluential
C29	Class	1,00	1,36	5,00	2,455	0,323	39	Uninfluential
C30	Experience in the sector (Years)	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C31	General condition of the ship	1,00	1,73	7,00	3,242	0,426	36	Uninfluential
C32	Delivery of cargo in undamaged	1,00	1,18	5,00	2,394	0,315	43	Uninfluential
C33	Hydro- meteorological	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C34	Technical- technological	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C36	Institutional	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C37	Bottom shell plating thickness	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C38	Side shell plating thickness	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C39	Main engine reliability	1,00	2,45	7,00	3,485	0,458	31	Uninfluential
C40	Auxiliary engine reliability	1,00	2,45	9,00	4,152	0,546	29	Uninfluential
C41	Loading pumps, valves	1,00	2,27	7,00	3,424	0,450	33	Uninfluential
C42	Discharging pumps, valves	1,00	1,18	5,00	2,394	0,315	43	Uninfluential
C43	Single skin vessel	1,00	2,09	7,00	3,364	0,442	35	Uninfluential
C44	Double skin vessel	1,00	1,18	5,00	2,394	0,315	43	Uninfluential
C45	Single bottom plating	1,00	1,36	5,00	2,455	0,323	39	Uninfluential
C46	Double bottom plating	1,00	1,73	5,00	2,576	0,339	37	Uninfluential
C47	Breadth of vessel	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C48	Level of toxicity	1,00	2,45	9,00	4,152	0,546	29	Uninfluential
C49	Level of radioactivity	1,00	3,36	9,00	4,455	0,586	28	Uninfluential
C50	Level of flammability	1,00	6,45	9,00	5,485	0,721	27	Moderate
C51	Insurance cost	1,00	7,00	9,00	5,667	0,745	26	Moderate
C52	Level of corrosiveness	1,00	1,00	3,00	1,667	0,219	47	Uninfluential
C53	Pollution prevention	1,00	1,18	5,00	2,394	0,315	43	Uninfluential

criterion C1 using equation (6):

$$S_{C1} = (8 + (0.6434 + 2{\cdot}0.6677 + 0.7041) - (0.0000 + 2{\cdot}0.0000 + 0.0000) - (0.0000 + 2{\cdot}0.0000 + 0.0000))/12 = 0.892$$

The score measures of the remaining factors were computed similarly. Hence, we determined the criteria weights with the help of equation (12) by applying an additive normalization technique.

c. Phase 3: Determination of the Preferences of the Alternatives.

In the next stage of the suggested MCDM framework, we determined the preferences of the alternatives concerning their performances by following the steps of the T2NFN GRA technique. The implementation steps of the model are presented in the following section.

Step 5: Decision makers $\xi = \{\xi_1, \xi_2, ..., \xi_{11}\}$ assessed the alternatives using the T2FNN scale shown in Table 13 to apply the proposed T2FNN GRA multicriteria model for evaluating the container vessel alternatives$A_i(i = 1, 2, ..., 7)$. DMs' linguistic evaluations are presented in Appendix-A.

The expert estimates of alternatives concerning criteria are presented in Appendix A.

Step 6: The values of the T2FNN significance of alternative concerning the evaluation criteria were identified using equation (13). The Type 2 fuzzy neutrosophic matrix showing the significant factors of the alternatives is shown in Appendix -B. In addition, the calculation of the T2NFN significance of the alternative A1 concerning the C1 criterion is presented in the following section:

$$\theta^{SF}_{A1-C1} = \left[\left(\theta^{T_T}_{11}, \theta^{T_I}_{11}, \theta^{T_F}_{11}\right), \left(\theta^{I_T}_{11}, \theta^{I_I}_{11}, \theta^{I_F}_{11}\right), \left(\theta^{F_T}_{11}, \theta^{F_I}_{11}, \theta^{F_F}_{11}\right)\right]$$

$$= \begin{cases} \theta^{T_T}_{11} = \{(0.70 + 0.70 + 0.35 + ... + 0.95) - (0.70{\cdot}0.70{\cdot}0.35{\cdot}...{\cdot}0.95)\}/11 = 0.690; \\ \theta^{T_I}_{11} = \{(0.75 + 0.75 + 0.35 + ... + 0.90) - (0.75{\cdot}0.75{\cdot}0.35{\cdot}...{\cdot}0.90)\}/11 = 0.686; \\ \theta^{T_F}_{11} = \{(0.80 + 0.80 + 0.10 + ... + 0.95) - (0.80{\cdot}0.80{\cdot}0.10{\cdot}...{\cdot}0.95)\}/11 = 0.722; \\ \theta^{I_T}_{11} = \{(0.20 + 0.20 + 0.75 + ... + 0.10) - (0.20{\cdot}0.20{\cdot}0.75{\cdot}...{\cdot}0.10)\}/11 = 0.000; \\ \theta^{I_I}_{11} = \{(0.20 + 0.20 + 0.75 + ... + 0.10) - (0.20{\cdot}0.20{\cdot}0.75{\cdot}...{\cdot}0.10)\}/11 = 0.000; \\ \theta^{I_F}_{11} = \{(0.25 + 0.25 + 0.80 + ... + 0.05) - (0.25{\cdot}0.25{\cdot}0.80{\cdot}...{\cdot}0.05)\}/11 = 0.000; \\ \theta^{F_T}_{11} = \{(0.10 + 0.10 + 0.50 + ... + 0.05) - (0.10{\cdot}0.10{\cdot}0.50{\cdot}...{\cdot}0.05)\}/11 = 0.000; \\ \theta^{F_I}_{11} = \{(0.15 + 0.15 + 0.75 + ... + 0.05) - (0.15{\cdot}0.15{\cdot}0.75{\cdot}...{\cdot}0.05)\}/11 = 0.000; \\ \theta^{F_F}_{11} = \{(0.20 + 0.20 + 0.65 + ... + 0.05) - (0.20{\cdot}0.20{\cdot}0.65{\cdot}...{\cdot}0.05)\}/11 = 0.000; \end{cases}$$

$$= [(0.690, 0.686, 0.722), (0.000, 0.000, 0.000), (0.000, 0.000, 0.000)]$$

Similarly, we computed the remaining values of the T2NFN significance of the alternative factor.

Step 7–8: By applying equation (6), the score measure alternatives were identified, and an aggregated basic T2NFN decision-matrix was formed, as seen in Table 14. The calculation of the score measure alternative A1 based on C1 is shown in the next section:

$$S_{A1-C1} = (8 + (0.690 + 2{\cdot}0.686 + 0.722) - (0.000 + 2{\cdot}0.000 + 0.000) - (0.000 + 2{\cdot}0.000 + 0.000))/12 = 0.899$$

Step 9. In this step, the T2FNN initial decision matrix elements are normalized with the help of equation (18). Then, the normalized matrix is formed, as presented in Table 15. Then, the absolute value of the elements was computed, and the absolute value matrix was formed, as given in Table 16.

Step 10–11. Next, we computed the grey relational coefficients by applying Eq (18). Then, the grey relational matrix was formed, as presented in Table 17. Afterwards, the grey relational matrix was weighted. In the final implementation step, the grey relational grade of each alternative concerning the selection criteria was computed using Eq (22). It also denotes the relative significance of each alternative, and the options are ranked by considering these grey relational grade scores. The final ranking performances of the decision alternatives are presented in Table 17. Table 18.

d. Phase 4: Validation test for the proposed T2NFN model.

We performed a comprehensive sensitivity analysis consisting of five stages for testing the validity of the proposed T2NFN GRA approach.

i. Examination of the impacts of the criteria weight changing on the ranking results.

In the first stage, we tested the stability and consistency of the model by changing the weights of each criterion. For this purpose, we formed 250 scenarios. In each scenario, the criterion's weight was reduced by 10%, and we continued till the criterion weight was equal to zero. The difference value was added to the other criteria equally to ensure that the sum of criteria weight should equal 1 in each scenario.

The proposed approach for testing the stability of the model can be accepted as a comprehensive evaluation on a vast scale since it proposes 250 scenarios, and it considers all probabilities about the impacts of modifications of the criteria weights on the final ranking results. By

Table 9
The final criteria set and definitions of the criteria.

Code	Criteria	Tanım
C1	Deadweight	It is the actual amount of weight in tonnes that a vessel can carry when loaded to the maximum permissible draught
C2	Ship Length	The maximum length of the ship between the ship's extreme points important for berthing purposes
C3	Ship's Loading Length	The ship's length measured at the waterline
C4	Ship's Width	The overall width of the ship measured at the widest point of the nominal waterline
C5	Draught	It is the vertical distance between the waterline and the bottom of the hull
C6	Container Carrying Capacity	The total carriage capacity of a vessel in terms of TEU
C7	Fuel consumption	It refers to the energy needs of a vessel for propulsion in terms of tons per day
C8	Scrapping Cost	It is incurring costs for scrapping a vessel when a vessel reaches to end of its economic life
C9	Transport Cost	The expenses a company incurs when it carries a unit of container in terms of TEU
C10	Purchase Cost	The expenses incurred by a company for purchasing a vessel
C11	Annual Maintenance and Repair Cost	Maintenance and repair expenses are costs incurred regularly to keep an asset working in its optimal condition
C12	Second-hand Market	It refers to the marketability of a vessel in the second-hand vessel market
C13-1	CO2	CO2 emissions are emissions stemming from the burning of fossil fuels
C13-2	NOx	It is a generic term for the nitrogen oxides that are most relevant for air pollution
C13-3	Sox	Sulfur oxide (SOx) emissions are mainly due to the presence of the sulfur compound in the fuel
C13-4	PM	It is a complex mixture of small liquid droplets and solid particulates suspended in the air
C14	Required Number of Staff	It refers to the number of crew required to operate a container vessel
C15	Block Coefficient	The ratio of the volume of the displacement of a ship to that of a rectangular block having the same length, breadth, and draft.
C16	Sea Margin	It describes how much-added power is required in operational conditions compared to the calm water conditions to maintain a speed in environmental and deteriorative effects.
C17	Engine Margin	That means that specified service speed is to be achieved with 85–90% of the MCR
C18	Ship Speed	Speed is sometimes incorrectly expressed as "knots per hour", which would mean "nautical miles per hour" and thus would refer to acceleration
C19	SMRC Power	It refers to ship power required for propulsion
C20	Maneuverability	The inherent ability of a vessel to change its course/path.
C21	The empty weight of ships	Lightship or lightweight measures the actual weight of the ship with no fuel, passengers, cargo, water, and the like onboard
C22	Economic Life	The economic life span of a ship in terms of year

contrast, most previous studies propose changing the weights of criteria in the first three ranks (Stanković et al., 2020), and this kind of evaluation can provide limited information on the stability and consistency of the proposed model. Because of that, we formed 250 scenarios by following the mathematical expressions proposed by (Görçün et al., 2021). The proposed algorithm is given in Eqs (23), (24), and (25).

$$w_{fv}^{1} = w_{pv}^{1} - \left(w_{pv}^{1}.m_{v}\right) \tag{23}$$

$$w_{nv}^{2} = \frac{\left(1 - w_{fv}^{1}\right)}{n-1} + w_{pv}^{2} \tag{24}$$

Table 10
The T2FNN linguistic scale for determining the significance of criteria.

Linguistic variables	T2FNN	Defuzzification values
Low (L)	[(0.20,0.30,0.20), (0.60,0.70,0.80), (0.45,0.75,0.75)]	0,324
Moderate Low (ML)	[(0.40,0.30,0.25), (0.45,0.55,0.40), (0.45,0.60,0.55)]	0,472
Moderate (M)	[(0.50,0.55,0.55), (0.40,0.45,0.55), (0.35,0.40,0.35)]	0,630
High (H)	[(0.80,0.75,0.70), (0.20,0.15,0.30), (0.15,0.10,0.20)]	0,894
Very High (VH)	[(0.90,0.85,0.95), (0.10,0.15,0.10), (0.05,0.05,0.10)]	1,000

$$w_{fv}^{1} + \sum w_{nv}^{2} = 1 \tag{25}$$

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

According to the results, the ranking performance of the best option (A6) has not changed for all scenarios and has remained in the same ranking position for 250 scenarios. In addition, there is no change in the ranking performances of the A3 and A4 alternatives. Besides, the ranking position of the A1 has changed for 22 scenarios (0.89), and A5 has remained in the same rank for 205 scenarios (0.82). Also, A7 has remained in the same rank for 217 scenarios (0.87). The average similarity ratio of the alternatives has been computed as 74.10%. As a result, the proposed MCDM framework is a consistent and stable T2NFN approach at a satisfactory level. Hence, it provides a reliable evaluation environment to the decision-makers for solving real-life decision-making problems.

ii. Comparative analysis.

In the second stage of SA, the proposed model results were compared with the ranking results of some popular multi-criteria approaches implemented in the current paper to test the validation of the T2NFN GRA technique in the following section. The T2NFN extensions of the applied MCDM framework were used for comparison, as the T2NFN extension of the GRA approach is applied in the current study: the Weighted Aggregated Sum Product Assessment (WASPAS) (Zavadskas et al., 2012), Combined compromise solution (CoCoSo) technique (Yazdani et al., 2019), Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS) method (Stević et al., 2020), Multiattribute Ideal-Real Comparative Analysis (MAIRCA) (Gigović et al., 2016), and Evaluation based on Distance from Average Solution (EDAS) techniques (Ghorabaee et al., 2015). We decided to apply these techniques to compare the ranking results, as they are popular MCDM frameworks and have provided very successful, reliable, and reasonable results in previous works. In addition, these approaches use similar implementation for normalizing the values in the initial decision matrix, and they have a similar algorithm.

Fig. 3 shows the comparison results among the ranking results of the applied T2NFN MCDM frameworks. According to the obtained results in Fig. 3, the ranking performance of the best option A6 has not changed concerning the results of the implemented decision-making techniques. Also, A7 has remained in the same rank for all applied T2NFN MCDM frameworks. Even though slight changes in the ranking performance of some alternatives have been observed, they cannot change the overall results. Correlations among all implemented models in the current paper are presented in Table 19.

According to the results given in Table 19, the T2NFN GRA and the T2NFN MARCOS, T2NFN MAIRCIA, and T2NFN WASPAS results are the same. As a result, almost all implemented MCDM tools confirmed the

Table 11
The selection criteria & the linguistic evaluations by the DMs.

The Selection Criteria												
		DMs										
Code	Criteria	1	2	3	4	5	6	7	8	9	10	11
C1	Deadweight	VH	VH	L	M	VH	M	L	M	VH	VH	VH
C2	Ship Length	M	VH	VH	VH	VH	H	VH	H	VH	VH	VH
C3	Ship's Loading Length	H	VH	VH	H	VH	M	VH	H	L	L	M
C4	Ship's Width	VH	VH	VH	VH	VH	M	H	H	ML	M	VH
C5	Draught	M	VH	VH	M	VH	M	VH	H	ML	ML	VH
C6	Container Carrying Capacity	M	H	VH	VH	VH	VH	VH	VH	VH	VH	VH
C7	Fuel consumption	VH	H	VH	VH	M	M	VH	M	VH	VH	VH
C8	Scrapping Cost	VH	H	VH	H	H	H	H	H	M	M	M
C9	Transport Cost	H	H	VH	VH	M	H	VH	H	L	L	VH
C10	Purchase Cost	VH	VH	VH	VH	VH	H	H	H	H	H	VH
C11	Annual Maintenance and Repair Cost	H	M	VH	VH	VH	VH	VH	H	VH	VH	VH
C12	Secondhand Market	H	M	L	VH	M	VH	L	VH	VH	VH	M
C13-1	CO2	M	ML	M	M	VH	ML	ML	ML	VH	VH	VH
C13-2	NOx	H	ML	ML	M	M	M	ML	ML	VH	VH	VH
C13-3	Sox	H	ML	L	M	M	ML	ML	ML	VH	VH	VH
C13-4	PM	M	L	ML	M	M	ML	ML	ML	VH	VH	VH
C14	Required Number of Staff	VH	L	M	VH	VH	M	M	M	ML	ML	M
C15	Block Coefficient	H	L	M	VH	VH	H	M	H	H	H	M
C16	Sea Margin	H	L	VH	VH	M	VH	VH	VH	H	H	VH
C17	Engine Margin	M	L	VH	VH	M	VH	VH	VH	VH	VH	VH
C18	Ship Speed	VH	L	VH	VH	L	M	VH	M	M	M	VH
C19	SMRC Power	H	L	VH	VH	M	M	VH	M	VH	VH	M
C20	Maneuverability	M	L	VH	ML	M	H	VH	H	L	L	VH
C21	Empty weight of ships	VH	L	M	ML	M	M	M	M	L	L	VH
C22	Economic Life	VH	L	VH	H	VH	VH	VH	VH	VH	VH	VH

Table 12
Aggregated expert evaluations of criteria and criteria weights.

Aggregated Value											
	T			I			F				
Criteria	T	I	F	T	I	F	T	I	F	Sc Vl.	Nr. Vl.
C1	0.6634	0.6677	0.7041	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.892	0.0399
C2	0.8329	0.7969	0.8519	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.940	0.0420
C3	0.6724	0.6676	0.6724	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.890	0.0398
C4	0.7605	0.7255	0.7657	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.915	0.0409
C5	0.6901	0.6586	0.6904	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.891	0.0399
C6	0.8405	0.8050	0.8689	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.943	0.0422
C7	0.7775	0.7555	0.8108	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.925	0.0414
C8	0.7340	0.7117	0.7029	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.905	0.0405
C9	0.6995	0.6856	0.6860	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.896	0.0401
C10	0.8387	0.7964	0.8251	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.938	0.0419
C11	0.8329	0.7969	0.8519	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.940	0.0420
C12	0.6543	0.6586	0.6815	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.888	0.0397
C13-1	0.6089	0.5681	0.5863	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.861	0.0385
C13-2	0.5998	0.5590	0.5636	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.857	0.0383
C13-3	0.5727	0.5363	0.5318	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.848	0.0379
C13-4	0.5454	0.5182	0.5182	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.842	0.0376
C14	0.5636	0.5636	0.5727	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.855	0.0382
C15	0.6812	0.6719	0.6586	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.890	0.0398
C16	0.7703	0.7431	0.7748	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.919	0.0411
C17	0.7617	0.7432	0.8054	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.921	0.0412
C18	0.6271	0.6406	0.6679	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.881	0.0394
C19	0.6813	0.6810	0.7127	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.896	0.0401
C20	0.5727	0.5772	0.5636	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.858	0.0383
C21	0.4818	0.5136	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.834	0.0373
C22	0.8216	0.7862	0.8511	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.937	0.0419

Table 13
T2FNN scale for evaluating 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)]
Moderate Bad (MB)	[(0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60)]
Moderate (M)	[(0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45)]
Moderate 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)]

final ranking results of the T2NFN GRA approach since the average Spearman's correlation coefficient (SCC) (Chatterjee et al., 2018) amounted to 0.979. There was a slightly lower correlation between the proposed model results and the T2NFN CoCoSo technique than the others, but it cannot be evaluated as low, as the SCC is equal to 0.929. According to the final results, it can be concluded that the proposed model is a robust and effective MCDM framework providing reliable and reasonable results.

iii. Examination of the impacts of the ζ value changing on the ranking results.

It is a significant issue whether changing the ζ value impacts the final ranking results, as it can influence the reliability and validity of the proposed model. Hence, we examined the impacts of changing the ζ value on the overall results. We aim to validate the ranking results obtained using the proposed model at the end of the evaluation process. For this purpose, we changed the value of ζ $_{\text{the}}$ coefficient giving scores between 0.10 and 1.00 in the third stage. For this purpose, we formed ten different scenarios, and in the fifth model, ζ it is determined as 0.5. According to the scenarios, the obtained grey relational grade (GRG) values in Fig. 4a and the ranking of the alternatives are presented in Fig. 4b.

When the obtained results are evaluated (Figs. 4a and 4b), while the ranking position of A6, the best alternative, has not changed, according to the scenarios, GRG values have been computed as 0.540 for the first scenario (i.e., the lowest; ζ=0.1) and 0.866 for the 10th scenario that is the highest (i.e., the lowest; ζ=1). (Refers Table 4 (a)). When the ranking performances of the alternatives are evaluated (Refers Table 4 (b)), the ranking performances of A2 and A5 have changed for$\zeta = 0.1$; it has not been observed that there are no changes in the ranking results for other scenarios.

iv. Test the resistance to the rank reversal problem.

Rank reversal is an Influential problem for many MCDM frameworks, and some MCDM techniques suffer from this problem. It can cause to discuss the reliability of the applied decision-making tools. Belton & Gear (Belton and Gear, 1983) also indicated that rank reversal is a fundamental problem for MCDM approaches. Also, according to Pamucar et al. (Pamučar et al., 2021), it can influence the robustness of an MCDM tool. Moreover, the rank reversal problem (in addition to some suggesting solutions) is one of the most popular and focused subjects in the existing literature (Schoner and Wedley, 1989; Leung and Cao, 2001; Totsenko, 2006; Ramanathan, 2006; Ren et al., 2007; te Jung et al., 2009; Kong, 2011; García-Cascales and Lamata, 2012; Maleki and Saadat, 2013; Iç, 2014; Pankratova and Nedashkovskaya, 2014; Bairagi et al., 2015; Sałabun, 2015; Ecer and Pamucar, 2021; Mukhametzyanov and Pamucar, 2018; Žižović et al., 2020). The final ranking results may change dramatically when an alternative is added or eliminated. Hence, it can affect the reliability of decision-making tools on a vast scale. Therefore, a robust and effective MCDM framework should not be influenced by the rank reversal problem, and it should provide a maximally consistent and stable decision-making environment. Thus, the resistance of a proposed model to the rank reversal problem should be tested to validate its reliability and applicability.

For this purpose, we tested the resistance of the model to the rank reversal problem. For this purpose, we eliminated the worst option in each scenario and examined the impacts of these modifications on the

Table 14
T2FNN initial decision matrix$\tilde{\aleph}$.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
A1	0,899	0,935	0,910	0,920	0,900	0,954	0,919	0,842	0,901	0,892	0,900	0,871
A2	0,916	0,945	0,870	0,914	0,889	0,956	0,925	0,819	0,878	0,872	0,903	0,829
A3	0,909	0,924	0,862	0,890	0,886	0,904	0,927	0,827	0,864	0,916	0,922	0,836
A4	0,897	0,868	0,845	0,852	0,855	0,884	0,915	0,888	0,844	0,918	0,925	0,865
A5	0,880	0,902	0,845	0,887	0,847	0,891	0,881	0,823	0,852	0,885	0,888	0,859
A6	0,901	0,938	0,895	0,877	0,858	0,959	0,899	0,837	0,864	0,882	0,893	0,866
A7	0,855	0,915	0,856	0,875	0,856	0,886	0,935	0,800	0,873	0,882	0,931	0,941

	C13-1	C13-2	C13-3	C13-4	C14	C15	C16	C17	C18	C19	C20	C21	C22
A1	0,895	0,900	0,883	0,905	0,862	0,891	0,901	0,878	0,848	0,882	0,793	0,829	0,919
A2	0,900	0,885	0,872	0,900	0,849	0,876	0,896	0,899	0,867	0,865	0,804	0,850	0,939
A3	0,889	0,880	0,854	0,887	0,847	0,848	0,876	0,873	0,917	0,844	0,863	0,878	0,927
A4	0,895	0,877	0,878	0,878	0,887	0,834	0,864	0,893	0,900	0,856	0,864	0,872	0,923
A5	0,854	0,868	0,850	0,858	0,867	0,833	0,842	0,867	0,887	0,868	0,866	0,846	0,867
A6	0,853	0,854	0,850	0,856	0,838	0,864	0,874	0,915	0,904	0,898	0,811	0,794	0,895
A7	0,860	0,858	0,851	0,851	0,848	0,826	0,857	0,892	0,885	0,914	0,835	0,802	0,900

Table 15
The normalized matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13-1	C13-2	C13-3	C13-4	C14	C15	C16	C17	C18	C19	C20	C21	C22
A1	0,980	0,989	1,000	1,000	1,000	0,995	0,957	0,948	0,933	0,977	0,987	0,925	0,950	0,947	0,960	0,936	0,971	1,000	0,930	0,959	0,925	0,964	0,916	0,956	0,978
A2	1,000	1,000	0,957	0,993	0,987	0,997	0,950	0,976	0,960	1,000	0,984	0,881	0,945	0,964	0,974	0,943	0,986	0,984	0,937	0,982	0,946	0,946	0,929	0,930	1,000
A3	0,991	0,977	0,948	0,967	0,984	0,943	0,948	0,966	0,977	0,949	0,962	0,888	0,958	0,970	0,995	0,957	0,989	0,953	0,961	0,953	1,000	0,923	0,997	0,894	0,986
A4	0,978	0,919	0,929	0,927	0,949	0,922	0,961	0,890	1,000	0,947	0,959	0,919	0,950	0,973	0,966	0,968	0,941	0,937	0,974	0,975	0,982	0,937	0,998	0,902	0,982
A5	0,960	0,954	0,929	0,964	0,941	0,930	1,000	0,972	0,991	0,985	1,000	0,913	0,998	0,984	1,000	0,992	0,966	0,936	1,000	0,947	0,968	0,950	1,000	0,934	0,923
A6	0,983	0,993	0,984	0,953	0,953	1,000	0,980	0,954	0,976	0,988	0,995	0,920	1,000	1,000	1,000	0,995	1,000	0,970	0,962	1,000	0,986	0,982	0,937	1,000	0,952
A7	0,932	0,968	0,941	0,952	0,951	0,924	0,939	1,000	0,965	0,989	0,952	1,000	0,991	0,996	0,998	1,000	0,987	0,928	0,983	0,975	0,965	1,000	0,964	0,990	0,958
Ref.Ser.	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

Table 16
The absolute value matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13-1	C13-2	C13-3	C13-4	C14	C15	C16	C17	C18	C19	C20	C21	C22
A1	0,020	0,011	0,000	0,000	0,000	0,005	0,043	0,052	0,067	0,023	0,013	0,075	0,050	0,053	0,040	0,064	0,029	0,000	0,070	0,041	0,075	0,036	0,084	0,044	0,022
A2	0,000	0,000	0,043	0,007	0,013	0,003	0,050	0,024	0,040	0,000	0,016	0,119	0,055	0,036	0,026	0,057	0,014	0,016	0,063	0,018	0,054	0,054	0,071	0,070	0,000
A3	0,009	0,023	0,052	0,033	0,016	0,057	0,052	0,034	0,023	0,051	0,038	0,112	0,042	0,030	0,005	0,043	0,011	0,047	0,039	0,047	0,000	0,077	0,003	0,106	0,014
A4	0,022	0,081	0,071	0,073	0,051	0,078	0,039	0,110	0,000	0,053	0,041	0,081	0,050	0,027	0,034	0,032	0,059	0,063	0,026	0,025	0,018	0,063	0,002	0,098	0,018
A5	0,040	0,046	0,071	0,036	0,059	0,070	0,000	0,028	0,009	0,015	0,000	0,087	0,002	0,016	0,000	0,008	0,034	0,064	0,000	0,053	0,032	0,050	0,000	0,066	0,077
A6	0,017	0,007	0,016	0,047	0,047	0,000	0,020	0,046	0,024	0,012	0,005	0,080	0,000	0,000	0,000	0,005	0,000	0,030	0,038	0,000	0,014	0,018	0,063	0,000	0,048
A7	0,068	0,032	0,059	0,048	0,049	0,076	0,061	0,000	0,035	0,011	0,048	0,000	0,009	0,004	0,002	0,000	0,013	0,072	0,017	0,025	0,035	0,000	0,036	0,010	0,042

Table 17
The grey relational matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13-1	C13-2	C13-3	C13-4	C14	C15	C16	C17	C18	C19	C20	C21	C22	GRG	Rank
A1	0,754	0,848	1,000	1,000	1,000	0,923	0,582	0,534	0,472	0,720	0,816	0,445	0,545	0,529	0,601	0,483	0,671	1,000	0,462	0,594	0,443	0,627	0,415	0,574	0,729	0,674	5
A2	1,000	1,000	0,581	0,901	0,826	0,947	0,545	0,716	0,600	1,000	0,789	0,333	0,521	0,626	0,695	0,512	0,815	0,789	0,485	0,769	0,523	0,527	0,456	0,460	1,000	0,701	3
A3	0,873	0,724	0,533	0,647	0,789	0,512	0,534	0,640	0,723	0,540	0,611	0,347	0,585	0,665	0,918	0,584	0,846	0,558	0,602	0,562	1,000	0,436	0,945	0,361	0,814	0,653	6
A4	0,735	0,423	0,455	0,449	0,541	0,432	0,606	0,353	1,000	0,532	0,590	0,425	0,547	0,692	0,639	0,651	0,505	0,485	0,697	0,707	0,769	0,486	0,972	0,378	0,772	0,593	7
A5	0,601	0,567	0,455	0,626	0,501	0,459	1,000	0,678	0,864	0,803	1,000	0,406	0,971	0,789	1,000	0,882	0,635	0,481	1,000	0,529	0,649	0,543	1,000	0,476	0,435	0,693	4
A6	0,781	0,893	0,792	0,561	0,558	1,000	0,748	0,563	0,715	0,832	0,926	0,429	1,000	1,000	1,000	0,918	1,000	0,669	0,613	1,000	0,815	0,771	0,487	1,000	0,556	0,784	1
A7	0,469	0,652	0,503	0,553	0,548	0,441	0,493	1,000	0,634	0,841	0,556	1,000	0,870	0,931	0,971	1,000	0,825	0,452	0,778	0,703	0,632	1,000	0,625	0,862	0,586	0,714	2

Table 18
The results of changing criteria weights.

	Different ranking (Scenarios)	The number of scenarios remained in the same rank	Similarity coefficient
A1	56–60, 75–80, 107–100, 188–190, 196–200, 229–230, 239–240	223	0.8920
A2	Many changes	54	0.2160
A3	There is no change	250	1.0000
A4	There is no change	250	1.0000
A5	4–10, 20, 48–50, 56–60, 75–80,107–110, 118–120, 167–170, 188–190, 196–200, 229–230, 239–240	205	0.8200
A6	There is no change	250	1.0000
A7	Many changes	65	0.2600
Average similarity coefficient			0.7411

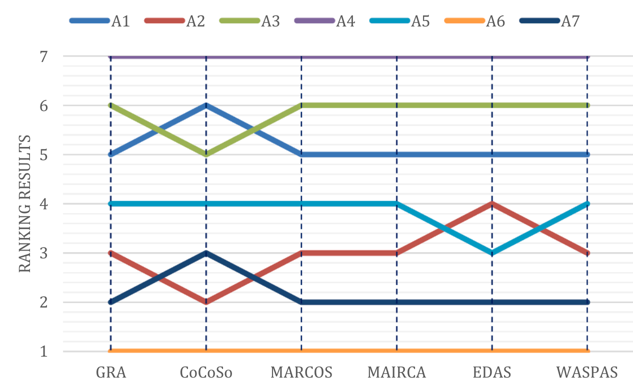


Fig. 3. Ranking of the alternatives concerning the applied MCDM techniques.

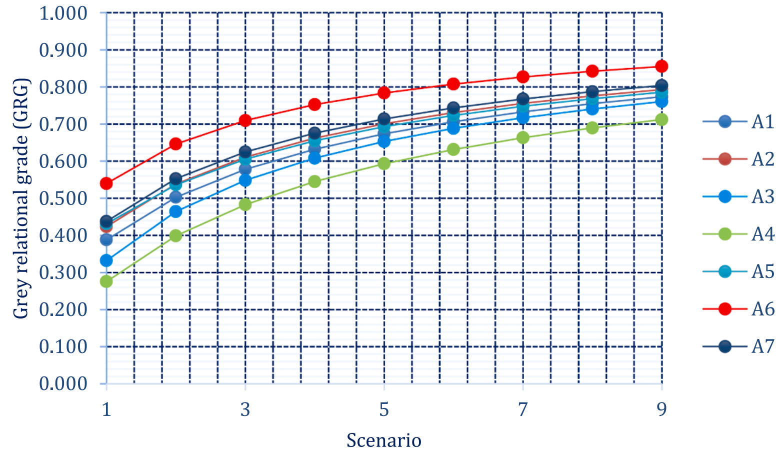
Table 19
Correlation coefficients among all implemented T2NFN MCDM frameworks.

	GRA	CoCoSo	MARCOS	MAIRCA	EDAS	WASPAS
GRA	1,000	0,929	1,000	1,000	0,964	1,000
CoCoSo	0,929	1,000	0,929	0,929	0,857	0,929
MARCOS	1,000	0,929	1,000	1,000	0,964	1,000
MAIRCA	1,000	0,929	1,000	1,000	0,964	1,000
EDAS	0,964	0,857	0,964	0,964	1,000	0,964
WASPAS	1,000	0,929	1,000	1,000	0,964	1,000

ranking results. For this purpose, we determined six scenarios. The final results obtained in this phase are presented in Fig. 5.

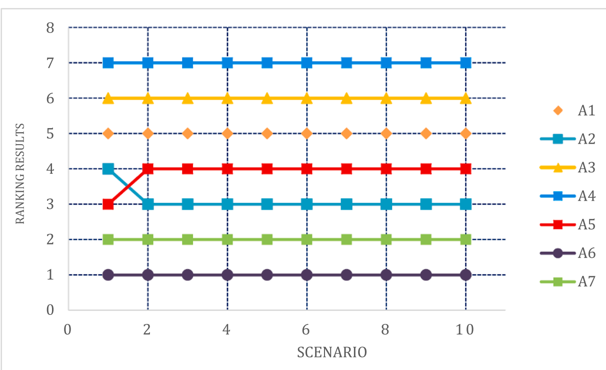
As shown in Fig. 5, there is no change in the ranking performances of the decision alternatives, and A6 has remained the best option for all scenarios. As a result, each phase of sensitivity analysis proves that the proposed T2NFN GRA approach is an applicable, robust, and powerful MCDM framework. Also, it is a consistent and stable framework for decision-makers. It has not observed a significant change in the final ranking results of the proposed model despite all excessive modifications performed by considering all probabilities by the authors. Hence, the results of SA approve the validity of the proposed model (Stanković et al., 2020; Stević et al., 2020). Thus, it presents a reliable and flexible decision-making environment to solve highly complicated decision-making problems encountered in real life.

v. Comparison of the results obtained by applying the different normalization techniques.



(a). The GRG value for each alternative concerning the ζ values between $0.1 \le \zeta \le 1$

Fig. 4a. The GRG value for each alternative concerning the ζ values between$0.1⩽\zeta⩽1$.



(b). Impacts of changing the ζ value on the ranking results

Fig. 4b. Impacts of changing the ζ value on the ranking results.

In this phase, the ranking results obtained using the proposed model are compared with those obtained by applying different normalization techniques. These normalization techniques are the Weitendorf's Linear Normalization (WL-N), which is the generic normalization approach of the classical GRA technique (Aytekin, 2021; Brauers and Zavadskas, 2006), the Vector Normalization (V-N) (Zavadskas and Turskis, 2008; Gardziejczyk and Zabicki, 2017; Aytekin, 2021), the Nonlinear (Peldschus) Normalization (NL(Peldschus)-N) (Aytekin, 2021; Brauers and Zavadskas, 2006). The ranking results of the alternatives obtained by applying these normalization approaches are presented in Fig. 6.

When the re-ranking of the alternatives shown in Fig. 6 is evaluated, it has been observed that the ranking performances of A2 and A5 have changed according to the results of the WL-N and NL (Peldschus)-N approaches, and there is no change in the ranking performances of the alternatives according to the results obtained by using V-N technique. When Spearman's correlation coefficient values among these ranking are computed, the correlation coefficient between the proposed approach and WL-N and NL (Peldschus)-N approaches is calculated as 0.964. Therefore, the obtained findings prove that the implemented normalization technique (J&K-N) in the proposed model can be used as an alternative normalization technique for the GRA approach.

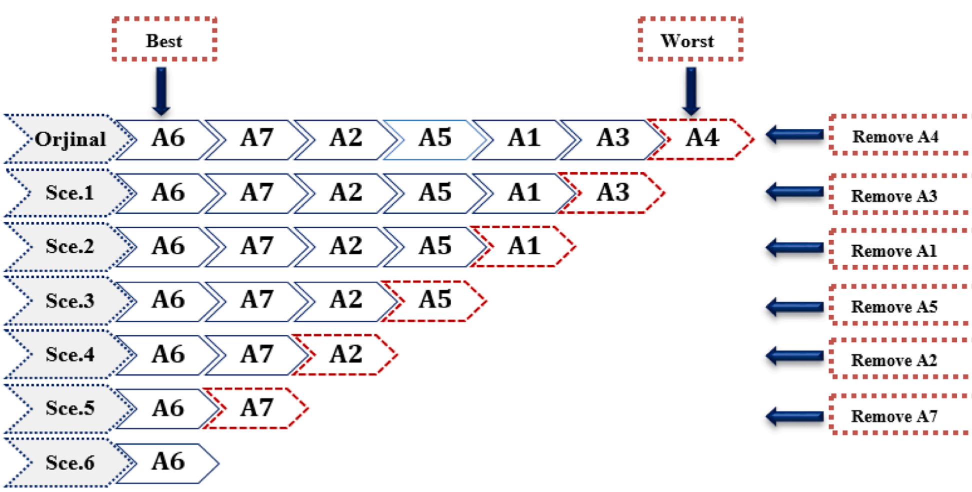


Fig. 5. Resistance of the proposed decision model to rank reversal problem.

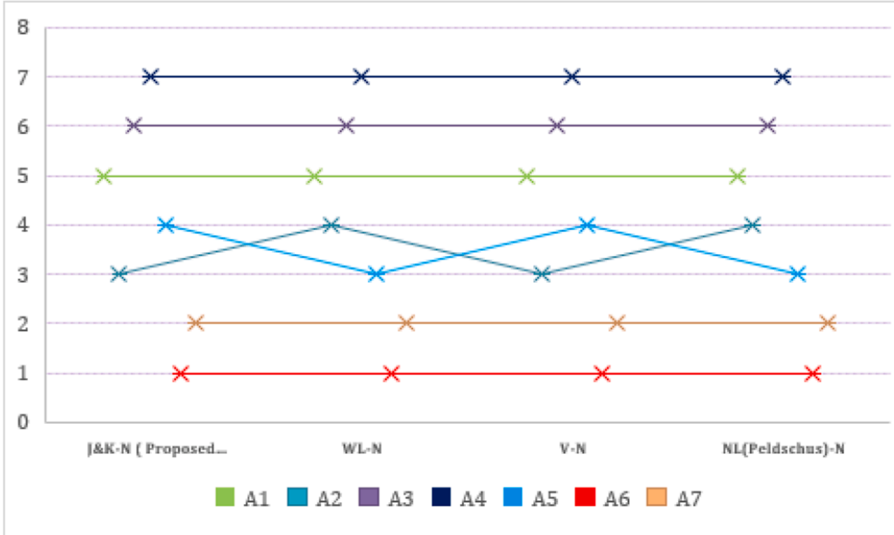


Fig. 6. Re-ranking the alternatives for different normalization techniques.

5. Results and discussions

When we examined the paper's main findings concerning the criteria significance, the container carriage capacity of a marine vessel is the most influential factor (Refer to Table 12). This finding is entirely reasonable and logical, as the criterion can affect the productivity and effectiveness of container shipping companies and their transport operations (Cullinane and Khanna, 2000). Productive, effective, and sustainable container shipping operations are the essential requirements for container shipping companies (Lam, 2015) and all stakeholders of the global supply chains. Hence, the container vessel's optimal carriage capacity can help create well-operated global logistics and transportation chains (Zavitsas et al., 2018).

Purchasing price identified as the second influential criterion is a cost factor, and it is still a significant factor for decision-makers. This finding confirms the main findings concerning purchasing costs of container vessels indicated in some studies carried out by authors in the literature (Voss, 2013; Lirn et al., 2004; Kuo et al., 2017). Remainders ranked as C6 > C2 = C11 > C10 > C22 > C7 > C17 > C16 > C4 > C8 > C9 > C19 > C1 > C5 > C15 > C3 > C12 > C18 > C13-1 > C20 > C13-2 > C14 > C13-3 > C13-4 > C21 (Refer. Table 12). As is seen, factors related to environmental pollution are in the rear ranks. Therefore, these criteria are not significant to select container vessels, as the container ships have lower emissions and environmental pollution compared to the other transport modes and types of maritime transportation. While container ships are responsible from releasing CO_2 emissions by %23, bulk carriers' share reached by %45 (Olmer et al., 2017), and while all container vessel emitted 140 million metric tons CO_2 per year, Bulk carriers emitted on average 440 million metric tons CO_2 (Statista, 2020).

When we compare the criteria reaching the degree of total effectivity, i.e., 1, (Refer to Table 17), A1 "ULCV" has provided C3, C4, and C5 criteria. A2 "New Panamax" provides C1, C2, C10, and C22, A2 is the best for C18, A3 is the appropriate option for C9, A4 "Panamax" is the appropriate alternative for the criteria C7, C11, C16, and C20. Besides, A5 "Suezmax is the best option for the criteria C7, C11, C16, and C20. Also, while A6 "Post Suezmax" provides C6, C13-1, C13-2, C13-3, C14, C17, and C21, "Post Malacca Max" provides C8, C12, and C19.

Post Suezmax is the best option when the overall ranking results are evaluated (Refers Table 17). Post Suezmax container vessels have many valuable advantages compared to the others. First, it has a very high container carriage capacity than others (Lomakina, 2018) except for post malaccamax type container vessels. Also, its purchasing price is extremely reasonable compared to the post malaccamax (Ham, 2005). Its fuel consumption is meagre and cannot be comparable with the fuel consumption of the post-Malacca-max type of container vessels. In addition, post Suezmax type container vessels provide excellent results for almost all selection criteria. Remain alternatives are ranked as A7 Post Malacca Max > A2 New Panamax > A5 Suezmax > A1 ULCV > A3 Post Panamax > A4 Panamax. Briefly, the managerial implications of the current study can be summarized as follows.

- Optimizing the selection of container vessels reduces the operational costs of container shipping companies. It can help increase the supply chain surplus (profits) for all stakeholders of the global supply chains, as it provides opportunities to create a more sustainable, productive, and effective transport chain.
- The presented criterion set is updated and suitable for container vessel selection for maritime shipping companies. The selection criteria were identified by following a methodological framework consisting of two parts: a detailed literature review and comprehensive fieldwork performed with highly experienced and extensive knowledge professionals. In addition, the extended version of the Delphi technique based on T2NFN sets has been implemented to identify the most influential criteria. The proposed approach provides maximally robust, reasonable, and logical results. Consequently, practitioners can focus on reasonable and realistic selection criteria when evaluating an appropriate container vessel using the proposed approach.
- The suggested decision-making tool in the current paper can make it easy to choose the right and optimal container ship types by eliminating the undesirable and improper alternatives.
- The paper has obtained findings and outputs that can guide container vessel designers and engineers to design and build more commercial and proper container vessels. They can consider the significant criteria identified in the current paper for designing suitable container vessels.
- The T2NFN GRA technique is a novel decision-making tool, and it has many valuable advantages compared to the traditional and popular many MCDM frameworks. It combines the advantages of the Grey Relational Analysis (GRA) and Type-2 neutrosophic fuzzy sets. The main advantages of the T2NFN set, GRA approach, and Type-2 sets are presented in the sub-section of 2.2, namely, the primary motivation of the work.
- The proposed model can capture and process uncertainties in an assessment process to evaluate the container vessels. Also, it can overcome the weakness of classical fuzzy sets, as it provides a more

flexible and comprehensive decision-making environment to the decision-makers.

- According to the sensitivity analysis results, the proposed model satisfactorily provides consistent and stable results (Refer. Phase 4). Hence, the T2NFN GRA approach is a robust, applicable, and decisive decision-making tool that can be applied to solve highly complicated decision-making problems
- The criteria weights can be identified by following the basic algorithm of the proposed model, and it is not required to use an additional weighting technique.

Although the current study has many valuable contributions to the literature, it is also required to consider some limitations of the paper. First, computations may take a long time and may seem complicated for practitioners. Hence, practitioners should be more careful during the computation process. In addition, researchers should select proper experts among highly experienced and have extensive knowledge professionals in the field, as the experts' evaluation and judgment may influence selecting the right and appropriate container vessels. Therefore, the selection process for experts is challenging and time-consuming, and researchers should be pretty patient during the process. Also, the experts' assessment may be entirely subjective and may reflect their judgments. Hence, researchers can continue to collect as much as possible information and data during the research process, and they can include these kinds of knowledge into the evaluation process to reduce the adverse effects of the subjective evaluations. We ranked the container vessel type alternatives by considering the eleven experts' evaluations in the current paper. When the experts are changed, it is possible to occur a slight change in the final ranking results. However, we do not expect significant changes, as the proposed model has many advantages, such as dealing with complex situations and uncertainties, insufficient information, lack of data, and weak knowledge.

Mathematical formulations of these advanced decision-making tools may seem complicated for practitioners in the maritime industry, and authors used traditional and classical MCDM frameworks. However, as it is not an entirely complex implementation, the proposed model's valuable advantages tolerate difficulties sourced from its partially complex structure.

6. Conclusions and recommendations for future works

The current paper deals with decision-making problems in evaluating and selecting container vessel types under uncertainty. It aims to fill two significant gaps in the existing literature noticed at the beginning of the research process. The first is related to the criteria set used in the previous works. Using different criteria sets in the previous studies carried out by authors proves that there are no commonly accepted criteria set in the literature. Moreover, it is also not sufficiently clear how these criteria were identified and which methodological frames were implemented to determine the criteria. It may cause reasonable doubts about the suitability of the criteria for real-world decision-making problems. Secondly, although many authors pointed out the existence of complicated situations and uncertainties in evaluation processes carried out to solve decision-making problems encountered in the maritime industry, they did not show a practical and robust decision-making model for overcoming these uncertainties. By keeping these gaps in mind, the current paper aims to fill these gaps as i) it presents a novel evaluation technique (i.e., the extended version of the Delphi technique based on T2NFN sets) to identify the criteria set. This approach can help identify the criteria more rationally and reasonably and eliminate the uninfluential criteria, and it can provide a methodological frame to determine the influential criteria that are suitable for real-world conditions. In addition, it can overcome many uncertainties existing in the assessment processes carried out to provide complete consensus among the experts and provides a practical algorithm for categorizing the existing criteria. ii) by considering the difficulties and requirements of container vessel type selection for practitioners and decision-makers, we proposed a novel MCDM framework based on type-2 neutrosophic fuzzy sets to combine the advantages of the neutrosophic numbers, type-2 fuzzy sets, and the grey relational analysis (GRA) approach. The proposed approach allows for capturing and processing many complicated predictable, and unpredictable uncertainties by associating the linguistic evaluations of the decision-makers with T2NFNs. Also, the grey relational coefficient parameters in the GRA approach provide an enormously flexible decision-making environment for decision-makers. Besides, it is a stable and consistent decision-making frame, as it cannot be influenced by many excessive modifications and changes as presented in the section of the validation test. A numerical illustration was performed to demonstrate the proposed model's implementation, and the T2NFN GRA approach was implemented to solve the container vessel type selection problem. The obtained results prove that the proposed decision-making tool can solve highly complicated decision-making problems encountered in various maritime industry fields.

Authors who carry out future works can extend the proposed model with the help of various fuzzy sets such as the intuitionistic fuzzy sets (Atanassov, 1986), fuzzy multisets (Yager, 1986), intuitionistic fuzzy sets of second type (Atanassov, 1989), neutrosophic fuzzy sets (Smarandache, 1999), non-stationary fuzzy sets (Garibaldi and Ozen, 2007) hesitant fuzzy sets (Torra, 2010), Pythagorean fuzzy sets (Yager, 2013), picture fuzzy sets (Cuong, 2014), q-rung fuzzy sets (Yager, 2017), Fermatean fuzzy sets (Senapati and Yager, 2020), spherical fuzzy sets (Gündoğdu and Kahraman, 2019) and circular intuitionistic fuzzy sets (Atanassov, 2020).

The current paper deals with container vessel selection. Still, the T2NFN GRA approach proposed in the current study can also be applied to solve decision-making problems in selecting other types of marine vessels such as dry bulk ships and crude oil tankers, chemical tankers, and Ro-Ro vessels, general cargo carriers. Besides, decision-makers can use some software such as excel and MATLAB to make computational operations easy. It may also be possible to develop new software as a decision support system.

Finally, it is required to keep in mind that the proposed methodological frame is proposed to select the best alternative among the container vessel types such as Panamax, Malaccamax, Suezmax, etc., and it is not explicitly deal with existing container vessels in the current market. Therefore, it presents a general frame to the literature and decision-makers. By considering the main outputs of the current paper, container shipping companies can carry out very optimal, reasonable, and logical decision-making processes; also, investors, shipbuilders, engineers, and designers may consider these outputs of the paper when they design a container vessel type and build them.

CRediT authorship contribution statement

Sarfaraz Hashemkhani Zolfani: Investigation, Writing – review & editing, Supervision, Methodology, Project administration. **Ömer Faruk Görçün:** Conceptualization, Validation, Investigation, Writing – original draft, Supervision, Project administration. **Pradip Kundu:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft. **Hande Küçükönder:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft.

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.

Appendix A. .

See Table A1.

Appendıx B. Aggregated decision matrix.

Table A1
Evaluations of the alternatives by decision-makers concerning the criteria.

Criteria	Dec.Mak.	A1	A2	A3	A4	A5	A6	A7	Criteria	A1	A2	A3	A4	A5	A6	A7	Criteria	A1	A2	A3	A4	A5	A6	A7	Criteria	A1	A2	A3	A4	A5	A6	A7
C1	DM1	G	MG	MB	B	M	VG	VG	C5	G	M	MB	B	MG	VG	VG	C9	VG	G	M	MB	G	MG	VG	C13-1	MB	M	G	VG	MG	M	VB
	DM2	G	MG	MB	B	M	VG	VG		G	M	MB	B	MG	VG	VG		VG	G	M	MB	G	MG	VG		MB	M	G	VG	MG	M	VB
	DM3	B	MB	M	M	MB	MB	B		VG	VG	VG	G	VG	VG	VG		VG	VG	VG	G	G	VG	VG		G	G	MG	M	M	MG	G
	DM4	M	VG	G	VG	VG	VG	M		M	M	M	B	M	B	M		M	M	VB	B	M	M	M		G	G	B	B	B	B	B
	DM5	G	VG	VG	G	M	M	M		G	G	G	G	M	B	VB		VG	G	VG	G	M	G	M		G	G	G	G	M	M	M
	DM6	G	VG	VG	G	M	M	M		G	G	G	G	M	B	VB		VG	G	VG	G	M	G	M		G	G	G	G	M	M	M
	DM7	MB	MB	M	M	MB	MB	B		VG	VG	VG	VG	VG	VG	VG		VG	VG	VG	G	G	VG	VG		G	G	MG	M	M	MG	G
	DM8	VG	VG	VG	VG	G	MG	MG		VG	VG	VG	VG	MG	MG	MG		M	MB	M	MG	MG	M	MG		MB	M	M	MB	MG	M	G
	DM9	VG	VG	VG	VG	VG	VG	VG		B	MB	MB	MB	MB	MB	MB		VB	VB	VB	VB	VB	VB	VB		VG	VG	VG	VG	VG	VG	VG
	DM10	G	VG	VG	VG	VG	VG	MG		B	MB	MB	MB	MB	MB	MB		VB	VB	VB	VB	VB	VB	VB		VG	VG	VG	VG	VG	VG	VG
	DM11	VG	VG	VG	VG	VG	VG	MG		VG	VG	VG	M	M	M	M		VG	VG	VG	VG	VG	VG	VG		G	G	G	G	G	G	G
C2	DM1	VG	MG	M	MB	G	VG	G	C6	VG	VG	MB	VB	MG	VG	VG	C10	MB	MG	VG	VG	MG	MB	MB	C13-2	M	MG	VG	VG	G	MG	B
	DM2	VG	MG	M	MB	G	VG	G		VG	G	MB	VB	MG	VG	VG		MB	MG	VG	VG	MG	MB	MB		M	MG	VG	VG	G	MG	B
	DM3	VG	VG	VG	MG	G	VG	VG		VG	VG	VG	G	G	VG	VG		G	G	VG	G	G	G	VG		G	G	MG	M	M	MG	G
	DM4	VG	VG	G	VG	VG	VG	M		M	G	VB	B	G	VG	G		VG	M	VB	B	M	M	VG		M	G	B	B	B	B	B
	DM5	VG	VG	G	M	M	M	M		VG	VG	G	G	M	VG	M		VG	G	G	G	M	M	M		VG	M	M	M	M	M	M
	DM6	VG	VG	G	M	M	M	M		VG	VG	G	G	M	G	M		VG	G	G	G	M	G	M		VG	M	M	M	M	M	M
	DM7	VG	VG	VG	G	G	VG	VG		VG	VG	VG	G	G	VG	M		G	G	VG	G	G	G	VG		G	G	MG	M	M	MG	G
	DM8	VG	VG	G	G	VG	G	G		VG	VG	G	G	MG	VG	MG		M	MB	M	G	VG	G	VG		MB	M	MB	MB	M	MB	M
	DM9	B	VG	VG	VG	VG	VG	VG		VG	VG	VG	VG	VG	VG	VG		MG	MG	G	G	G	G	G		VG	VG	VG	VG	VG	VG	VG
	DM10	B	VG	VG	VB	VB	VG	VG		VG	VG	VG	VG	VG	VG	MG		MG	MG	G	G	G	G	M		VG	VG	VG	VG	VG	VG	VG
	DM11	VG	VG	VG	VG	VG	VG	VG		VG	VG	VG	VG	VG	VG	M		VG	VG	VG	VG	VG	VG	MG		G	G	G	G	G	G	G
C3	DM1	VG	M	MB	VB	MG	VG	G	C7	VB	B	G	VG	M	MB	VG	C11	M	MG	VG	VG	G	M	MB	C13-3	VB	B	MG	VG	M	MB	VB
	DM2	VG	M	MB	VB	MG	VG	G		VB	B	G	VG	M	MB	VG		M	MG	VG	VG	G	M	MB		VB	B	MG	VG	M	MB	VB
	DM3	VG	VG	VG	G	G	VG	VG		VG	VG	G	G	MG	VG	VG		VG	VG	G	M	M	VG	VG		G	G	MG	M	M	MG	G
	DM4	G	G	G	VG	VG	M	M		VG	G	VG	M	G	M	VG		G	M	M	M	G	B	VG		M	G	B	B	B	B	B
	DM5	VG	G	G	VG	M	VG	M		VG	VG	G	M	M	G	B		VG	VG	G	VG	M	M	G		VG	M	M	M	M	M	M
	DM6	VG	G	G	VG	M	VG	M		VG	VG	G	M	M	B	B		VG	G	G	VG	M	M	G		VG	M	M	M	M	M	M
	DM7	VG	VG	VG	G	G	VG	VG		VG	VG	G	G	MG	VG	VG		VG	VG	G	M	M	VG	VG		G	G	MG	M	M	MG	G
	DM8	VG	VG	G	M	G	G	G		VG	G	M	G	G	G	VG		M	MB	MB	G	MG	G	VG		MB	M	MB	M	M	M	M
	DM9	VB	VB	VB	VB	VB	VB	VB		G	VG	VG	VG	VG	VG	VG		MG	G	VG	VG	VG	VG	VG		VG	VG	VG	VG	VG	VG	VG
	DM10	VB	VB	VB	VB	VB	VB	VB		G	VG	VG	VG	VG	VG	VG		MG	G	VG	VG	VG	VG	VG		VG	VG	VG	VG	VG	VG	VG
	DM11	M	M	M	M	M	M	M		VG	VG	VG	VG	VG	VG	VG		VG	VG	VG	VG	VG	VG	VG		G	G	G	G	G	G	G
C4	DM1	G	M	MB	MB	MG	VG	VG	C8	MB	M	G	VG	MG	B	VB	C12	G	MG	M	B	MG	VG	VG	C13-4	MB	M	G	VG	G	MG	VB
	DM2	G	M	MB	MB	MG	VG	VG		MB	M	G	VG	MG	B	VB		G	MG	M	B	MG	VG	VG		MB	M	G	VG	G	MG	VB
	DM3	VG	VG	VG	G	G	VG	VG		M	M	MB	MG	MG	M	M		MB	MB	M	MB	M	MB	G		G	G	MG	M	M	MG	G
	DM4	G	VG	G	VG	VG	B	B		G	M	B	G	M	M	M		G	M	VB	M	G	B	VG		G	G	B	B	B	B	B
	DM5	VG	VG	G	M	VG	M	M		VG	MG	M	VG	M	VG	M		VG	M	M	G	M	M	VG		VG	G	G	M	B	M	M
	DM6	VG	VG	G	M	VG	M	M		VG	MG	M	VG	M	VG	M		VG	M	M	G	M	M	VG		VG	G	G	M	B	M	M
	DM7	VG	VG	VG	G	G	VG	VG		M	M	MB	MG	MG	M	M		MB	MB	M	MB	M	MB	G		G	G	MG	M	M	MG	G
	DM8	VG	VG	G	G	G	G	G		M	G	M	MG	M	MG	M		MB	G	MB	VG	MG	M	G		MB	M	MB	M	M	M	M
	DM9	B	MB	MB	MB	MB	MB	MB		B	B	M	M	M	M	M		MG	MG	VG	VG	VG	VG	VG		VG	VG	VG	VG	VG	VG	VG
	DM10	B	MB	MB	MB	MB	M	MB		B	B	M	M	M	M	M		MG	MG	VG	VG	VG	VG	VG		VG	VG	VG	VG	VG	VG	VG
	DM11	VG	VG	VG	M	M	M	M		M	M	M	M	M	M	M		M	M	M	M	M	M	M		G	G	G	G	G	G	G
Criteria	Dec.Mak.	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	Criteria	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	Criteria	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**								
C14	DM1	MG	MG	G	VG	MG	MG	M	C18	G	MG	VG	G	VG	VG	G	C22	G	VG	VG	VG	MG	M	MB								
	DM2	MG	MG	G	VG	MG	MG	M		G	MG	VG	G	VG	VG	G		G	VG	VG	VG	MG	M	MB								
	DM3	G	G	MG	M	M	M	G		MG	MG	VG	VG	VG	MG	MG		VG	VG	VG	MG	MG	VG	VG								
	DM4	VG	VG	G	VG	VG	G	G		M	M	G	B	M	G	M		G	G	VB	VB	G	VB	M								
	DM5	G	M	M	G	G	M	B		M	G	G	G	M	G	G		M	G	G	G	B	M	M								
	DM6	G	M	M	G	G	M	B		M	G	G	G	M	G	G		M	G	G	G	B	M	M								
	DM7	G	G	MG	M	M	M	G		MG	MG	VG	VG	VG	MG	MG		VG	VG	VG	G	MG	VG	VG								
	DM8	B	M	M	G	VG	G	VG		MB	VG	MG	G	MB	VG	VG		VG	G	M	VG	MG	VG	VG								
	DM9	MB	MB	M	M	M	M	M		MB	MB	M	M	M	M	M		G	G	VG	VG	VG	VG	VG								

(*continued on next page*)

Table A1 (*continued*)

Criteria	Dec.Mak.	A1	A2	A3	A4	A5	A6	A7	Criteria	A1	A2	A3	A4	A5	A6	A7	Criteria	A1	A2	A3	A4	A5	A6	A7	Criteria	A1	A2	A3	A4	A5	A6	A7
	DM10	MB	MB	M	M	M	M	M		MB	MB	M	M	M	M	M		G	G	VG	VG	VG	VG	VG								
	DM11	M	M	M	M	M	M	M		VG	VG	VG	VG	VG	VG	VG		VG	VG	VG	VG	VG	VG	VG								
C15	DM1	VG	G	MB	B	MG	MG	MG	C19	VG	MG	VB	B	MG	G	VG																
	DM2	VG	G	MB	B	MG	MG	MG		VG	MG	VB	B	MG	G	VG																
	DM3	G	G	MG	M	M	M	G		G	G	MG	G	VG	G	VG																
	DM4	M	VG	G	VB	G	G	B		MG	M	B	B	M	M	B																
	DM5	G	M	G	G	M	G	B		M	M	G	G	M	G	G																
	DM6	G	M	G	G	M	G	B		M	M	G	G	M	G	G																
	DM7	G	G	MG	M	M	M	G		G	G	MG	G	VG	G	VG																
	DM8	G	G	MG	VG	MG	VG	M		MB	G	G	M	MG	G	G																
	DM9	M	M	MG	MG	MG	MG	MG		G	G	G	G	G	G	G																
	DM10	M	M	MG	MG	MG	MG	MG		G	G	G	G	G	G	G																
	DM11	M	M	M	M	M	M	M		M	M	M	M	M	M	M																
C16	DM1	M	M	M	M	M	M	M	C20	MB	B	VG	G	MG	VB	VB																
	DM2	M	M	M	M	M	M	M		MB	B	VG	G	MG	VB	VB																
	DM3	VG	VG	G	MG	MG	G	VG		MG	MG	G	VG	VG	MG	MG																
	DM4	VG	G	G	M	G	M	M		MB	M	M	M	M	M	M																
	DM5	G	G	G	G	M	G	B		VB	M	M	M	G	M	G																
	DM6	G	G	G	G	M	G	B		VB	M	M	M	G	M	G																
	DM7	VG	VG	G	MG	MG	G	VG		MG	MG	G	VG	VG	MG	MG																
	DM8	VG	VG	MG	VG	MG	G	G		B	B	M	MG	M	G	VG																
	DM9	M	M	MG	MG	MG	MG	MG		B	B	B	B	B	B	B																
	DM10	M	M	MG	MG	MG	MG	MG		B	B	B	B	B	B	B																
	DM11	G	G	G	G	G	G	G		G	G	G	G	G	G	G																
C17	DM1	MB	G	MB	G	G	G	G	C21	MB	M	G	VG	MG	B	VB																
	DM2	MB	G	MB	G	G	G	G		MB	M	G	VG	MG	B	VB																
	DM3	VG	VG	MG	MG	MG	G	VG		MG	MG	G	G	G	MG	MG																
	DM4	G	G	G	B	M	G	M		MB	G	G	M	G	M	M																
	DM5	M	M	G	G	M	G	M		G	G	G	M	M	VB	B																
	DM6	M	M	G	G	M	G	M		G	G	G	M	M	VB	B																
	DM7	VG	VG	MG	MG	MG	G	VG		MG	MG	G	G	G	MG	MG																
	DM8	VG	VG	MG	VG	MG	G	MG		M	M	MB	G	M	G	G																
	DM9	MG	MG	G	G	G	G	G		B	B	B	B	B	B	B																
	DM10	MG	MG	G	G	G	G	G		VB	MB	B	B	B	B	B																
	DM11	G	G	G	G	G	G	G		G	G	G	G	G	MG	G																

	C1									—	C5								
A1	0,690	0,686	0,722	0,000	0,000	0,000	0,000	0,000	0,000	…	0,699	0,704	0,700	0,000	0,000	0,000	0,000	0,000	0,000
A2	0,799	0,708	0,782	0,000	0,000	0,000	0,000	0,000	0,000	…	0,672	0,641	0,717	0,000	0,000	0,000	0,000	0,000	0,000
A3	0,744	0,695	0,769	0,000	0,000	0,000	0,000	0,000	0,000	…	0,690	0,614	0,717	0,000	0,000	0,000	0,000	0,000	0,000
A4	0,695	0,690	0,686	0,000	0,000	0,000	0,000	0,000	0,000	…	0,586	0,559	0,555	0,000	0,000	0,000	0,000	0,000	0,000
A5	0,645	0,613	0,690	0,000	0,000	0,000	0,000	0,000	0,000	…	0,573	0,505	0,582	0,000	0,000	0,000	0,000	0,000	0,000
A6	0,735	0,668	0,743	0,000	0,000	0,000	0,000	0,000	0,000	…	0,623	0,559	0,555	0,000	0,000	0,000	0,000	0,000	0,000
A7	0,595	0,554	0,550	0,000	0,000	0,000	0,000	0,000	0,000	…	0,600	0,541	0,591	0,000	0,000	0,000	0,000	0,000	0,000
	C6										**C10**								
A1	0,878	0,845	0,882	0,000	0,000	0,000	0,000	0,000	0,000	…	0,708	0,641	0,717	0,000	0,000	0,000	0,000	0,000	0,000
A2	0,876	0,853	0,886	0,000	0,000	0,000	0,000	0,000	0,000	…	0,640	0,586	0,649	0,000	0,000	0,000	0,000	0,000	0,000
A3	0,731	0,686	0,749	0,000	0,000	0,000	0,000	0,000	0,000	…	0,740	0,739	0,776	0,000	0,000	0,000	0,000	0,000	0,000
A4	0,645	0,654	0,650	0,000	0,000	0,000	0,000	0,000	0,000	…	0,734	0,751	0,776	0,000	0,000	0,000	0,000	0,000	0,000
A5	0,685	0,654	0,703	0,000	0,000	0,000	0,000	0,000	0,000	…	0,645	0,640	0,690	0,000	0,000	0,000	0,000	0,000	0,000
A6	0,889	0,863	0,893	0,000	0,000	0,000	0,000	0,000	0,000	…	0,631	0,627	0,703	0,000	0,000	0,000	0,000	0,000	0,000
A7	0,663	0,641	0,690	0,000	0,000	0,000	0,000	0,000	0,000	…	0,663	0,613	0,690	0,000	0,000	0,000	0,000	0,000	0,000
…																			
	C18										**C22**								
A1	0,568	0,505	0,595	0,000	0,000	0,000	0,000	0,000	0,000	…	0,734	0,747	0,794	0,000	0,000	0,000	0,000	0,000	0,000
A2	0,645	0,559	0,636	0,000	0,000	0,000	0,000	0,000	0,000	…	0,805	0,809	0,850	0,000	0,000	0,000	0,000	0,000	0,000
A3	0,748	0,734	0,782	0,000	0,000	0,000	0,000	0,000	0,000	…	0,784	0,766	0,803	0,000	0,000	0,000	0,000	0,000	0,000
A4	0,681	0,699	0,722	0,000	0,000	0,000	0,000	0,000	0,000	…	0,779	0,753	0,789	0,000	0,000	0,000	0,000	0,000	0,000
A5	0,659	0,641	0,703	0,000	0,000	0,000	0,000	0,000	0,000	…	0,659	0,582	0,577	0,000	0,000	0,000	0,000	0,000	0,000
A6	0,717	0,694	0,743	0,000	0,000	0,000	0,000	0,000	0,000	…	0,681	0,672	0,709	0,000	0,000	0,000	0,000	0,000	0,000
A7	0,645	0,640	0,690	0,000	0,000	0,000	0,000	0,000	0,000	…	0,717	0,668	0,743	0,000	0,000	0,000	0,000	0,000	0,000

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