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ORIGINAL PAPER

Sustainability performance assessment of freight transportation modes using an integrated decision-making framework based on m-generalized q-neutrosophic sets

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Abstract

The freight transport industry is one of the primary sectors responsible for excessive energy consumption and greenhouse gas emissions. Restructuring international and domestic freight transport chains based on sustainability and green transportation is critical for practitioners and policymakers to reduce pressure on the logistics and transportation industries. This study aims to develop a mathematical model for selecting the most appropriate transportation type, and accordingly, the optimal route in transportation operations to improve the sustainability performance of the freight transportation industry. Therefore, the main goal is to choose the most suitable route and transportation type which contributes to create a more eco-friendly and sustainable transportation system. For this purpose, Neutrosophic Number-based Delphi (NN-Delphi), m-Generalized q-Neutrosophic Sets (mGqNSs)-based Stepwise Weight Assessment Ratio Analysis (MGqNS-SWARA) and mGqNSs-based Additive Ratio Assessment (mGqNS-ARAS) are developed and implemented to set the influential criteria, compute the weights of these criteria, and identify the sustainability performance of the freight mode variants, respectively. According to the final results, "Cargo security" and "Accident rates" are the most important criteria with a relative importance score of 0.0237, contributing to the sustainability of load transport modes. Moreover, "Maritime Transport Mode" is identified as the most sustainable transportation type with a relative importance score of 0.7895. Finally, it is revealed that there is a positive relationship between maritime transport and sustainability.

Keywords Sustainability performance · Freight transportation · Decision-making framework · NN-Delphi · MGqNS-SWARA method · MGqNS-ARAS method

1 Introduction

The rapid growth of the world population in the recent century and dramatic changes in customers' consumption habits have led to severe increases in demand for natural resources. While supply chains try to meet these requirements of their customers on time and at a satisfactory level, simultaneously, they must also meet their needs by outsourcing by managing less costly, efficient, and productive logistics operations. Consequently,

Extended author information available on the last page of the article supply chains have become more dependent on logistics service providers and freight transport operators. Moreover, today, many enterprises use outsourcing to conduct logistics and transport activities with higher quality and lower cost (Ejem et al. 2021). Executives in supply chains mostly rely on the ability of the freight transport companies concerning speed, flexibility, agility, and providing low-cost services when they make strategic and operational decisions regarding their supply chain operations. In this respect, the speed of deliveries and the efficiency of transportation operations in global markets play an essential role (Ližbetin and Stopka 2020). Freight transport operators combine several complicated operations (Muerza et al. 2017) and activities to respond to the requirements of the customers and other stakeholders of the supply chains efficiently. Accordingly, freight operators are critical collaborators of the supply chains, which deliver materials, i.e., raw materials and semi-finished goods to industrial users and finished products to consumers, with trustworthiness, effectiveness, and reasonable cost. Hence, they are essential to the supply chain, linking all partners, e.g., suppliers, producers, service providers, retailers, and consumers (Kumar and Anbanandam 2020b).

Although the freight transport system has critical importance for the supply chains, it causes problems that negatively influence modern international society's environmental, social, and economic sustainability. The freight transport industry's large share in environmental pollution is chiefly responsible for emission-based air pollution (Babaei et al. 2022). Transportation activities are the most significant contributors to environmental pollution in many countries (D'Orso et al. 2023). The transport industry critically impacts almost all sides of human life in contemporary societies (Yannis et al. 2020). Besides, transport leads to adverse changes in all environmental elements due to its effects, such as harmful greenhouse gases, noises, and loss of ecosystems (Broniewicz and Ogrodnik 2020). An essential part of the studies in the relevant literature is in consensus that transportation operations are the primary sources of emissions even though there are slight differences concerning the share of transport activities. While much research works, e.g., (He et al. 2017; Kim et al. 2011; Li and Zhang 2020) stated that the share of transportation is around 24%, Wang et al. (2022) claimed that its share is 27%.

Moreover, according to some claims, the share of logistics activities in environmental pollution will be 22% higher than the recent years' level by 2050 (Gandhi et al. 2022). In addition, the share of road-based freight transport systems has increased in recent years and continues to grow. Transporting loads by road causes many challenges and technical problems. First, road transportation is impractical for reloading cargo and can only produce practical solutions in short distances (Stopka 2022). It makes it challenging to render reasonable and applicable solutions to environmental problems. According to some studies in the literature, road freight transportation is responsible for 40% of emissions in urban areas. Even worse, the share of road freight transport continues to increase globally despite all efforts of international bodies and governments. While in EU countries, the share of road freight transport is around 60%, its share is over 80% in many other countries (Gandhi et al. 2022).

Furthermore, the negative externalities of freight transportation are not limited to environmental pollution. The transport industry is the chief consumer of global energy sources (Kumar and Anbanandam 2020c). Moreover, there is a positive correlation between demands for freight transportation and energy consumption concerning energy consumption. If the demand increases, energy consumption is also increased. In addition, there is a meaningful correlation between energy usage and environmental pollution, as the transportation industry uses vehicles, i.e., trucks, lorries, marine vessels, and other means of transport dependent on fossil-based fuels.

Moreover, freight transport activities also cause various negative externalities such as accidents, noise pollution, and traffic congestion, aside from environmental pollution and excessive energy usage. From this perspective, it is seen that the overall sustainability performance of the freight transportation industry is poor, and it may cause losses in reputation and money for companies, aside from health problems, losses of lives, injuries arising from freight transportation's negative externalities (Giannakis and Papadopoulos 2016). Therefore, integrating sustainability strategies into the overall strategy of freight transport companies has become critical and essential for these firms. In addition, international bodies, governments, and the final consumers have increased pressure on freight transport companies to set sustainability policies and strategies. They look forward to the freight transport industry taking action to accelerate this integration process. Thus, by considering the requirements of sustainable development, the re-designed freight transport system may play a significant role for all stakeholders of the supply chains. Furthermore, sustainability practices in the freight transport industry can be an essential strategy to enhance the freight transport companies' ability of competitiveness (Piecyk and McKinnon 2010).

On the other hand, improving the freight transport industry's sustainability performance can help to provide balanced economic development aside from assisting in re-creating an inhabitable environment by reducing environmental pollution. Besides, it can help to reduce costs, increase revenue and customer loyalty, and enhance the quality of life of humans (Kumar and Anbanandam 2022). In addition, global markets and consumers demand involvement in developing sustainable practices from parties of supply chains (Peña-Orozco et al. 2023). Though sustainability strategies provide competitive advantages for freight transport companies, no sustainability practices are commonly implemented in the freight transport industry yet. One of the main reasons for that is that restructuring a sustainable transport chain decreases the complexities of transportation operations and makes it challenging to manage the transport processes (Golnar and Beškovnik 2022). Only a few logistics companies, such as DHL, FedEx, UPS, Ekol, Borusan Logistics Co., and Mars Logistics Co. are attempting to integrate sustainability practices into the overall strategies of their company. These attempts are valuable, but they are not adequate to generalize the sustainability practices for the freight transport industry. In addition, practitioners in the freight transport industry cannot get sufficient support from the scientific world to appraise the sustainability performance of their companies and logistics activities, as many authors try to tackle the sustainability of transport activities primarily focused on urban and public transportation sustainability. Hence, the literature on freight transport sustainability is extraordinarily limited and scarce.

The selection of routes and transportation modes is one of the critical factors influencing the sustainability performance of a freight transport company. Both selections are correlated, and another influences each choice. In addition, route and mode selection can affect the overall sustainability performance of freight transport companies, as they impact energy utilization, the environmental performance of the freight transport operations, and other negative externalities. Steadieseifi et al. (2014) highlighted the significance of the mode selection and expressed that freight transport modes set the costs and environmental and social risks. However, they did not consider the impact of route selection on the sustainability performance and connections between route and mode selection. In addition, most of the studies in the relevant literature handled transport mode selection from the perspective of cost optimization and productivity maximization, and they overlooked critical sustainability performance criteria. There are a few studies dealing with freight transport mode selection, and these studies could not associate mode and route selection in freight transport operations concerning the sustainability perspective. Besides, some papers repeated well-known expressions concerning the superiorities and disadvantages of transport modes.

The present study claims strong correlations between route and transport mode selection in the freight transport industry (Chen and Zhang 2023). It aims to provide an efficient and trustworthy procedure to evaluate route and transport mode selection in freight transport operations concerning sustainability performance. The potential versatility of the proposed methodology in this work can be anticipated in artificial intelligence, including enhancing an intelligent decision support framework and developing an expert decision-making tool under indeterminacy and complex uncertainty. For this purpose, the current study proposes a decision-making model based on the m-Generalized q-Neutrosophic Sets (mGqNSs). In addition, it develops a novel Delphi method extended based on the NSs to identify the criteria that will be used to assess the sustainability performance of freight transport companies concerning route and mode selection.

The rest of the manuscript is structured as follows. In Sect. 2, an extensive literature review is conducted to set the existing gaps and contributions of the previous works. Besides, we collected the criteria used in the prior studies to assess them in the process conducted for identifying the criteria. In Sect. 3, the proposed model and its basic procedure are demonstrated. In Sect. 4, the proposed model is executed to evaluate the contributions of the route and mode selection to the sustainability performance of freight transport companies.

Furthermore, the validity and robustness of the model are evaluated using an extensive sensitivity analysis. In Sect. 5, the study's findings are evaluated and discussed, and the study's management implications and theoretical contributions are outlined. Section 6 indicates the main findings, research limitations, and recommendations to the researchers conducting the following works on this subject.

2 Literature review

By performing a simple search in well-known scientific databases with some keywords such as freight transport sustainability, we found 57 research studies dealing with sustainable freight transportation. Nevertheless, most of these works introduced sustainability policies and regulations released by international bodies. They presented projections and estimations of these regulations' impacts on the logistics companies' sustainability performance, defined as the compatibility of economic, social, and environmental objectives of a freight transport firm's core business activity to achieve its maximum value. Furthermore, we noted 21 research works in the relevant literature examining the sustainability performance of freight transport and transport companies using various decision-making frameworks and procedures. These studies are reviewed in Table 1.

Thirty-five previous studies dealing with sustainability in freight transportation in the relevant literature were collected. In 12 of them, the authors preferred to use diverse fuzzy sets, such as classical fuzzy sets (6), Intuatistic FSs (2), Grey Numbers (2), and Rough FSs (2), to handle uncertainties existing in the relevant industry. In addition, the most used weighting procedure is the DEMATEL (5), and it is followed by the AHP (4), BWM (3), DEA (2), Entropy (2), and SWARA (1), respectively. When the frameworks were used to identify the preference ratings of the options, while some methods such as DEA, TOPSIS, MARCOS, VIKOR and ANP were used twice, some approaches, such as CoCoSo, GRA,

Table 1 Studies dealing with the sustainability of freight transportation using decision-making tools

References	Subject	Methodology
Babaei et al. (2022)	Sustainability of urban and freight transport	Fuzzy DEA
Pamucar et al. (2022)	Sustainable transportation	Rough ACZEL–ALSINA
Kokkinos et al. (2022)	Hydrogen storage station location selection	IHFs based method
Thompson et al. (2022)	Freight transportation mode selection	Fuzzy AHP and TOPSIS
Wang et al. (2022)	Measuring road transport sustainability	Entropy and CoCoSo
Pajić et al. (2022)	Sustainable transportation mode selection	SWARA and MARCOS
Fulzele et al. (2019)	Selection of transportation modes	GRA-IF
Gandhi et al. (2022)	Sustainable rail freight transportation	Systematic scientometric review
Dwivedi et al. (2022)	Analysis of recovery measures	Grey DEMATEL
de Freitas et al. (2021)	Sustainable freight transport	Fuzzy logic
Mrabti et al. (2021)	Sustainable freight transport	MILP
Singh et al. (2021)	Barriers to green freight transportation	ISM-gDEMATEL
Pathak et al. (2021)	Priorities for sustainable freight transportation	FER
Huang & Han (2021)	Freight transport environmental sustainability	Entropy and TOPSIS
Choudhary et al. (2021)	Evaluating the risk exposure	Interval 2-tuple linguistic model
Broniewicz & Ogrodnik (2021)	Sustainable Transport	DEMATEL REMBRANDT, VIKOR
Fulzele & Shankar (2021)	Sustainable freight transport	FER
Yazdani et al. (2020)	Development of a decision support framework	Rough DEMATEL and MABAC
Dwivedi et al. (2020)	Investigating the transport flexibility measures	Fuzzy BWM
Kumar & Anbanandam (2020a)	Sustainable intermodal freight transport	Grey DEMATEL and ANP
Kumar & Anbanandam (2020b)	Freight transport service providers	IF-AHP and IF-VIKOR
Kumar & Anbanandam (2020c)	Prioritisation of green logistics	Fuzzy BWM
Kumar & Anbanandam (2022)	Sustainable intermodal freight transport	Index-based approach
Kumar Dadsena et al. (2019)	Risk evaluation and mitigation	FMEA
Ghadir et al. (2022)	Impacts of COVID-19 outbreak on supply chain risks	FMEA
de Campos et al. (2019)	Road freight transport' impacts on sustainability	Evaluation method
Pathak et al. (2019)	Sustainable freight transportation systems	Delphi, TISM and fuzzy AHP

Table 1 (continued)

References	Subject	Methodology
Buldeo Rai et al. (2018)	Sustainable urban freight transport	Hierarchical structuring
Shankar et al. (2018)	Sustainable freight transportation systems	IFNs-D-number theory
Buldeo Rai et al. (2017)	Sustainable urban freight transport	Systematic review
Bouhana et al. (2015)	Personalized itinerary search systems	Case-based reasoning (CBR)
Stoilova (2018)	Evaluation of the efficiency of intermodal transport	PROMETHEE
Stoilova (2019)	Assessment of alternative transport policies	SIMUS
Callefi et al. (2022)	Technology-enabled capabilities in road transport	Systematic literature review
Kumar et al. (2019)	Sustainable freight transportation	Systematic literature review
Koohathongsumrit & Meethom (2021)	Route selection in multimodal transportation	DEA
Koohathongsumrit & Chankham (2023)	Route selection in multimodal supply chains	Fuzzy BWM-MARCOS
Graham & Rogers (2013)	Impacts of freight transportation networks	AHP and ANP

AHP, Analytical Hierarchy Process; ANP, Analytical Network Process; BWM, Best Worst Method; CBR, Case-Based Reasoning; CoCoSo, Combined Compromise Solution; DEA, Data Envelopment Analysis; DEMATEL, Decision Making and Trial Evaluation Laboratory; FER, Fuzzy Evidential Reasoning; FMEA, Failure Modes and Effects Analysis; GRA-IF, Grey Relational Analysis based on Intuitionistic Fuzzy sets; IHF, Intuitionistic Hesitant Fuzzy; IF-AHP, Intuitionistic Fuzzy sets-based AHP; IF-VIKOR, Intuitionistic Fuzzy sets-based VIKOR; IFN, Intuitionistic Fuzzy Number; MABAC, Multi-Attributive Border Approximation area Comparison; MARCOS, Measurement Alternatives and Ranking according to COmpromise Solution; MILP, Mixed-Integer Linear Programming; REMBRANDT, Ratio Estimation in Magnitudes or deci-Bells to Rate Alternatives which are Non-Dominated; SWARA, Stepwise Weight Assessment Ratio Analysis; TISM, Total Interpretive Structural Modelling; TOPSIS, Technique of Order Preference Similarity to the Ideal Solution; VIKOR, VIseKriterijumska Optimizacija I Kompromisno Resenje

MABAC and AHP were applied once to rank alternatives. Table 2 compares the previously implemented tools in the literature and the proposed model.

When the literature is reviewed in detail, it is noticed that there are limited papers published till 2020. After this year, the interest in this topic as well as the number of studies on transportation sustainability using fuzzy Multi-Criteria Decision-Making (MCDM) tools has increased. According to Pathak et al. (2021), recent studies published in the literature show that researchers' interest has continued to grow in evaluating the sustainability performance of the transportation industry. Although increasing interest in sustainable transportation is positive and promising, it is too soon to say that the relevant literature can successfully evaluate the impacts of freight transport mode selection on sustainability performance. To put it more explicitly, the literature involving the studies focusing on the sustainability of freight transportation is still in its infancy, as there are critical and severe research gaps, which look forward to filling in the relevant literature. These theoretical and managerial gaps are given in detail in the subsequent section. Table 2 compares the previously implemented tools in the literature and the proposed model.

2.1 Research gaps

First, the research community has shown less attention to the sustainability performance of freight transportation than urban and public transportation sustainability for all countries when the literature is reviewed in detail. Local authorities and municipalities record much information and data concerning urban transit, and all data and information related to urban transportation are collected in a single centre. Hence, obtaining more robust and reliable data concerning urban transportation is more straightforward than freight transportation. As there are many authorities in freight transportation, such as highways authority, general administration of transport, local authorities, customs, and other authorities in transit countries, collecting data from many authorities to appraise the sustainability performance of freight transportation is too laborious and challenging.

Additionally, many studies dealing with freight transport mode selection evaluate the alternative routes by considering only cost minimization and benefit maximization. It was skewed as it did not consider many influential criteria and factors. In addition, the researchers focused on economic measures more than other factors, such as environmental and social criteria, in previous studies to evaluate the overall performance of the freight transport industry. Hence, a few studies on the overall sustainability performances of freight transport companies with an integrated approach and holistic view are in the literature. Most of the work concentrated on economic or environmental factors and neglected the social criteria. However, social sustainability factors such as accidents, congestion, noise pollution, and employment are not less important than environmental and economic criteria.

On the other hand, the research society neglected intermodal, combined, railway, and airway transportation, and researchers more often focused on the sustainability performances of the road and maritime transportation modes. Furthermore, the number of studies making comparative analyses concerning sustainability performance among the freight transportation modes is scarce. Moreover, none of the studies in the literature associate the impacts of freight transport routes and mode selection with each other and the sustainability performance of the freight transport companies. However, freight transport mode and route selection directly affect emissions and environmental pollution, and it has become a research object concerning international and intermodal transportation (Bask and

Table 2 Comparison between features of the proposed procedure and implemented approaches

Features	Proposed model	Fuzzy	–	–	–	Fuzzy	Rough	IF
		AHP	Entropy	SWARA	Entropy	BWM	DEMATEL	-
		TOPSIS	CoCoSo	MARCOS	TOPSIS	MARCOS	MABAC	GRA
Handle uncertainties	Very High	Fair	No	No	No	Fair	High	High
Resistance to the RRP	Very High	Low	Fair	Fair	Low	High	Fair	Fair
Long lasting computations	Low	Very High	Fair	Fair	High	Fair	Very High	Fair
Flexibility	Very High	Very Low	High	High	Low	High	Low	Fair
Required time	Less	Very Long	Fair	Fair	Fair	Fair	Long	Fair
Check model parameters	Yes	No	No	No	No	No	No	Yes
Complexity	Very low	High	Low	Low	Fair	Low	High	Low
Stability	Very High	Very Low	High	High	Low	Fair	Low	Low
Capture complex vagueness	Strong	Weak	No	No	No	Weak	Fair	Fair
Capture unpredictable vague	Strong	No	No	No	No	No	No	No
Changing criteria weights	Very Stable	Not applied	Stable	Stable	Not applied	Stable	Not applied	Not applied

Rajahonka 2017). Besides, Himanen et al. (2005) argued that mode choice should be added to the evaluation process as an item concerning the security and safety of individuals, i.e., the social sustainability factor. Besides, the number of criteria presented in each study in the relevant literature differs, and the authors considered many criteria in these preceding works. It proves no consensus in the literature concerning the criteria for evaluating freight transport companies' sustainability performances. Moreover, we have very little information about how these criteria employed in the previous works were specified, and only it is possible to estimate how these factors were set. Identifying the right and suitable criteria using a mathematical tool is critical and vital for adequately structuring the decision-making problem.

In addition, most previous studies preferred to use qualitative approaches or subjective and objective decision-making frameworks to appraise the sustainability performance of the freight transportation industry. In most of the studies using mathematical models to evaluate freight transport sustainability, the authors preferred to utilize subjective decision analysis techniques such as AHP, ANP, and DEMATEL and objective decision-making frameworks, such as Entropy, MABAC, DEA, VIKOR, TOPSIS, CoCoSo and GRA. Some studies employed the extensions of decision-making approaches based on classical fuzzy sets to process the uncertainties. When these approaches are evaluated in general, there are some drawbacks and structural problems, and they cannot meet the requirements concerning sustainability performance analysis of the freight transportation industry. First, some approaches (e.g., AHP, ANP, TOPSIS, GRA) frequently used in the literature are severely fragile and unresistant to the rank reversal problem (Kong et al. 2016; Aires and Ferreira 2018). This weakness of these techniques increases doubts about the trustworthiness of the acquired results applying these approaches. In addition, studies applying the subjective and objective frames did not consider existing complex uncertainties arising from undetermined, vague, and imprecise information. Besides, some decision-making approaches have complicated and laborious algorithms requiring tremendous computations and comparisons.

2.2 Motivations and objectives of the work

The primary motivation for the study is to find a logical and reasonable solution for the decision-making problem encountered by international freight transportation companies concerning the selection of sustainable routes and transport modes. These companies are international road freight transport firms and members of the International Transporter Association. Besides, all of them are also members of the EU countries' working group, which is the sub-committee in the association. Senior executives of the working group had identified a set of transport modes and routes, but they were unsure which option could contribute to the sustainability performance of the freight transport company at a higher level. They sought assistance from our research team to address this problem by employing a practical and trustworthy mathematical model. We accepted this invitation and started an investigation and research process to solve this problem by generating a board of experts involving the senior executives of international road freight transport firms. Thus, the developed model has been implemented to treat a real-life, critical and essential problem of the Turkish freight transport industry, which has the most extended road freight vehicle fleet.

Furthermore, the study aims to fill theoretical and managerial literature gaps. Furthermore, it presents an integrated procedure that can be utilized as a roadmap by practitioners who are in the freight transportation industry. Thus, Decision-Makers (DMs) can integrate sustainability practices proposed into their primary corporate strategy by following the basic procedure suggested in the present work. Moreover, it associates route and mode selection practices concerning the sustainability performance of the freight transport companies. In addition, the current work is based on a real-life decision problem faced by practitioners in Turkish freight transport companies and freight forwarders. These executives of the freight transport companies aimed to create a measure to evaluate their sustainability performances and asked for help from our research team to provide them with a practical and robust evaluation tool to measure their sustainability performances.

In this process, a set of research questions were identified by researchers for structuring the research process properly as follows:

(***RQ1***) Why is freight route selection significant in improving sustainable practices for freight transportation companies?
(***RQ2***) How can identifying the significance of the freight transport mode options influence the choice of sustainable freight transport routes?
(***RQ3***) How can sustainability practices concerning route and transport mode selection be integrated into companies' core business strategies?
(***RQ4***) How do decision-making models based on advanced fuzzy sets provide advantages for appraising the sustainability performance of a freight transport company in an incredibly complicated uncertain environment?
(***RQ5***) What are the influential and critical factors to measure their effects on the sustainability performance of the freight transport modes?

By considering these research questions, the research objectives are demonstrated as follows: (*I*) to introduce a novel and robust methodological framework to correctly identify the criteria for structuring the assessment process, (*II*) to demonstrate the impacts of the criteria on sustainability performance by measuring the relative significance of the criteria with the help of the proposed approach, (*III*) to show how can the sustainability practices concerning the route and transport mode selection be integrated into the core business strategies of freight transport firms, (*IV*) to show how a robust and practical decision-making framework that can overcome enormously complex decision-making problems can provide advantages to enhance the sustainability performance of a freight transport company, and (*V*) to demonstrate the influential criteria affecting the sustainability performance of the freight transport firms concerning route and transport mode selection.

After the first meeting with these top managers, we suggested evaluating the companies' route and model selection practices because both selection processes largely influence the sustainability performance of a freight transport company (details of this process are presented in Sect. 4). Hence, the current study presents a practical and reliable algorithm to check the mode and route selection impacts on the overall sustainability performance. For this purpose, it proposes to create freight transport routes by considering the sustainable performances of the transportation modes. For this purpose, modes with higher sustainability performance are preferred to form the transport chain, and the most appropriate route alternative is identified as the combination involving the most sustainable transportation modes. From this perspective, the current work is unique, as it provides a robust and practical decision-making model based on mGqNSs to measure the impacts of mode and route selection in the freight transport industry concerning the sustainability performance of the companies. In addition, it presents a methodological frame, namely the extended version of the Delphi approach, with the help of NSs to identify suitable and correct criteria.

3 Materials and methods

The Neutrosophic Set (NS) was first offered by Smarandache (1998) and has been usefully employed in numerous studies over the following years. Many of these studies focus on solving MCDM problems and various essential applications in computational and artificial intelligence (Chen 2022; Singh et al. 2023). It allows us to solve the decision problem with varying degrees of Truth (T), Indeterminacy (I), and Falsity (F). NS is distinct from Intuitionistic Fuzzy Sets (IFSs), which can treat uncertainty independently of truth and indeterminacy, possess a more adaptable framework, and handle a tremendous amount of information. NSs are the generalizations of classical fuzzy sets (Entemann 2002), IFSs (Varshney et al. 2022), q-Rung Orthopair Fuzzy Sets (q-ROFSs) (Ecer et al. 2023), and Pythagorean Fuzzy Sets (PFSs) (Chen 2022). Based on this concept, Saha et al. (2020) expanded this generalization and proposed terminology for the mGqNSs. Single-Valued Neutrosophic Sets (SVNSs), Interval-Valued Neutrosophic Sets (IVNSs), and Type-2 Neutrosophic Sets (T2NSs) are treated as helpful in dealing with uncertainty, vagueness, and non-rigid bounds of the initial information, but they lack sufficient generality and flexibility in some circumstances. They cannot cover all recently suggested cases of fuzzy sets. In this regard, mGqNS eliminates these constraints and can generalize fuzzy sets, PFS, IFS, q-ROFS, SVNS, single-valued n-hyperspherical NS, and single-valued spherical NS (Aytekin et al. 2022; Turskis et al. 2022; Zavadskas et al. 2020).

Some MCDM methods, such as CoCoSo-mGqNS (Turskis et al. 2022), Multi-Objective Optimization on the basis of a Ratio Analysis plus the full MULTIplicative form-mGqNS (MULTIMOORA-mGqNS) (Zavadskas et al. 2020), Weighted Aggregated Sum Product ASsessment-mGqNS (WASPAS-mGqNS) (Semenas et al. 2021), and Preference Ranking Organization METHod for Enrichment Evaluations-mGqNS (PROMETHEE-mGqNS) (Baušys et al. 2021), have extensions defined under mGqNS. On the other hand, we developed a new methodology including NN-Delphi, Stepwise Weight Assessment Ratio Analysis-mGqNS (MGqNS-SWARA), and Additive Ratio ASsessment-mGqNS (MGqNS-ARAS) to assess the sustainability performance of freight transportation modes due to its flexibility in dealing with uncertainty in this study. The main reason for using such a methodology is to ensure that the evaluations of DMs unfamiliar with MCDM are as effective and accurate as possible. Preferred methods are structured to allow unfamiliar experts to understand implementation steps easily. It also contains features for processing the uncertain information collected from experts. Additive Ratio Assessment (ARAS) involves providing the best choice or ranking by comparing the variants with the optimal solution based on the existing options (Aytekin 2022). Furthermore, SWARA and ARAS are employed in performance measurements of transportation companies (Radović et al. 2018), freight distribution concept selection (Jovčić et al. 2019), sustainable transportation mode selection from the perspective of a freight forwarder (Pajić et al. 2022), investigation of empty container shortage (Toygar et al. 2022), logistic centre location selection (Turskis & Zavadskas 2010). On the other hand, this study proposes a new framework for modelling uncertain and imprecise information. In addition to these advantages, MGqNS-ARAS proposed in this research allows for the effective and flexible modelling of uncertainties. Besides, Neutrosophic Number-based Delphi (NN-Delphi) is used to determine the criteria set and extension of SWARA based on mGqNSs; i.e., mGqNS-SWARA is developed to weigh the criteria. In this regard, the following subsections included explanations about mGqNS, NN-Delphi, MGqNS-SWARA, and MGqNS-ARAS.

3.1 Preliminary investigation on mGqNSs

A mGqNs can be defined as $\psi = \{\langle x, \zeta(x), \vartheta(x), \eta(x) : x \in U\rangle\}$, where $\zeta, \vartheta, \eta : U \rightarrow [0, r]$, $0 < r \leq 1, 0 \leq (\zeta(x))^q + (\vartheta(x))^q + (\eta(x))^q \leq \frac{3}{m}, 0 \leq \zeta(x), \vartheta(x), \eta(x) \leq 1$, and $m, q \geq 1$. In this form, $\zeta(x)$ denotes the m-generalized truth membership degree, $\vartheta(x)$ describes the m-generalized indeterminacy membership degree, and $\eta(x)$ is the m-generalized falsity membership degree. Thus, $\psi = \langle \zeta, \vartheta, \eta \rangle$ is described as m-Generalized q-Neutrosophic Number (mGqNN), where m and q can be considered to represent different fuzzy sets (Aytekin et al. 2022; Saha et al. 2020; Zavadskas et al. 2020).

Suppose $\psi_1 = \langle \zeta_1, \vartheta_1, \eta_1 \rangle$ and $\psi_2 = \langle \zeta_2, \vartheta_2, \eta_2 \rangle$ are two mGqNNs, and λ is a positive real number. Then, the operations between mGqNNs are denoted below (Aytekin et al. 2022; Turskis et al. 2022; Zavadskas et al. 2020):

$$\psi_1 \oplus \psi_2 = \left\langle \left(1 - \left(1 - \zeta_1^q\right)\left(1 - \zeta_2^q\right)\right)^{\frac{1}{q}}, \vartheta_1 \vartheta_2, \eta_1 \eta_2 \right\rangle, \tag{1}$$

$$\psi_1 \oplus \psi_2 = \left\langle \zeta_1 \zeta_2, \left(1 - \left(1 - \vartheta_1^q\right)\left(1 - \vartheta_2^q\right)\right)^{\frac{1}{q}}, \left(1 - \left(1 - \eta_1^q\right)\left(1 - \eta_2^q\right)\right)^{\frac{1}{q}} \right\rangle, \tag{2}$$

$$\lambda * \psi_1 = \langle \left(1 - \left(1 - \zeta_1^q\right)^{\lambda}\right)^{\frac{1}{q}}, \vartheta_1^{\lambda}, \eta_1^{\lambda} \rangle, \tag{3}$$

$$\psi_1^{\lambda} = \left\langle \zeta_1^{\lambda}, \left(1 - \left(1 - \vartheta_1^q\right)^{\lambda}\right)^{\frac{1}{q}}, \left(1 - \left(1 - \eta_1^q\right)^{\lambda}\right)^{\frac{1}{q}} \right\rangle, \tag{4}$$

$$\psi_1^c = \langle \eta_1, 1 - \vartheta_1, \zeta_1 \rangle. \tag{5}$$

The mGqNN score function is computed based on Eq. (6):

$$S(\psi) = \frac{3 + 3\zeta^q - 2\vartheta^q - \eta^q}{6}. \tag{6}$$

The m-Generalized q-Neutrosophic Weighted Averaging Aggregation (mGqNWAA) operator is described using Eq. (7), where $\psi_k = \langle \zeta_k, \vartheta_k, \eta_k \rangle$, $k = 1, \ldots, p$ (Aytekin et al. 2022; Saha et al. 2020):

$$\text{mGqNWAA}\left(\psi_1, \ldots, \psi_p\right) = \left\langle \left(\frac{3}{m} - \prod_{k=1}^{p}\left(\frac{3}{m} - \zeta_k^{\frac{qm}{3}}\right)^{w_k}\right)^{\frac{3}{qm}}, \prod_{k=1}^{p} \vartheta_k^{w_k}, \prod_{k=1}^{p} \eta_k^{w_k} \right\rangle. \tag{7}$$

The m-Generalized q-Neutrosophic Weighted Geometric Aggregation (mGqNWGA) operator is described using Eq. (8):

$$\mathrm{mGqNWGA}(\psi_1,\ldots,\psi_p)=\left\langle\prod_{k=1}^{p}\zeta_k^{w_k},\left(\frac{3}{m}-\prod_{k=1}^{p}\left(\frac{3}{m}-\vartheta_k^{\frac{qm}{3}}\right)^{w_k}\right)^{\frac{3}{qm}},\left(\frac{3}{m}-\prod_{k=1}^{p}\left(\frac{3}{m}-\eta_k^{\frac{qm}{3}}\right)^{w_k}\right)^{\frac{3}{qm}}\right\rangle, \quad (8)$$

where $w=\left(w_1,\ldots,w_p\right)^T$ is the weight vector of $(\psi_1,\ldots,\psi_p)$ in Eqs. (7)–(8), while the conditions $w_k\geq 0$ and $\sum_{k=1}^{p}w_k=1$ should be met.

3.2 Identified criteria by applying the NN-Delphi approach

After determining the criteria set evaluated with the help of the proposed approach, the experts performed linguistic assessments for each criterion concerning the compatibility of these criteria to the decision-making problems. Next, the deneutrosophication of acquired Neutrosophic Number (NN) values was generated by applying the score function given in Eq. (6). Then, these evaluations were collected by the researchers (Görçün et al. 2023), and NNs, acquired by aggregating with the help of Eq. (11) were defuzzified by using Eq. (8). Afterwards, defuzzified values are standardized using Eq. (9) and each criterion's score is computed:

$$\Theta_i=\frac{\omega_i}{max\left(\omega_i\right)}, \quad (9)$$

Finally, criteria are categorized into three groups by considering Θ_i score of each criterion. Intervals for the classification of the criteria are represented in Table 3.

3.3 Computing the weights of the criteria

Consulting expert opinions to determine the weight values of the criteria is a common approach in MCDM problems. On the other hand, because experts are generally unfamiliar with MCDM methodology, there is a greater need for practical, simple-to-understand, and applicable methods for determining the weight values of the criteria. SWARA, suggested by Keršulienė et al. (2010), with numerous crisps and fuzzy set extensions, is a feasible choice in this context. For this purpose, a new extension of SWARA defined under mGqN sets will be included in this study. The studies of Salamai (2021), Ayyildiz (2022), and Rani et al. (2020) were employed in the development of MGqNS-SWARA. The MGqNS-SWARA processing steps are summarized below.

Step 1. The criteria to be taken into account in the decision problem are specified. In this study, NN-Delphi was utilized to determine the criteria.

Step 2. The experts assess the importance levels of criteria using the linguistic terms in Table 4 (Aytekin et al. 2022). Linguistic evaluations are denoted as $\varsigma_j^{(k)}=\langle\zeta_j^{(k)},\vartheta_j^{(k)},\eta_j^{(k)}\rangle$. Here, $\varsigma_j^{(k)}$ stands for the linguistic assessments of kth expert for jth criterion, where the criteria $(j=1,\ldots,n)$, and experts $(k=1,\ldots,p)$.

Step 3. Weight values are assigned to the evaluations of experts. For this purpose, linguistic terms in Table 2 are used, and then weight values are calculated with Eq. (10), where $\xi_k=\left(\zeta_k,\vartheta_k,\eta_k\right)$ stands for the knowledge and experience of the k $^{\text{th}}$ expert (Aytekin et al. 2022):

Table 3 Categories for the criteria concerning freight transport sustainability

Degrees	Interval
Uninfluential	$0 \leq \Theta_i < 0.5$
Moderate	$0.5 \leq \Theta_i < 0.81$
Influential	$0.81 \leq \Theta_i \leq 1.00$

$$\acute{\upsilon}_k = \frac{\frac{3+3\zeta_k^q-2\vartheta_k^q-\eta_k^q}{6}}{\sum_{k=1}^{p}\frac{3+3\zeta_k^q-2\vartheta_k^q-\eta_k^q}{6}} \quad (k = 1, 2, .., p), \tag{10}$$

Step 4. Integrated importance levels for criteria (ι_j) are calculated based on mGqN-WGA as follows:

$$\varrho_j = \left\langle \prod_{k=1}^{p} \zeta_j^{(k)^{\acute{\upsilon}_k}}, \left(\frac{3}{m} - \prod_{k=1}^{p}\left(\frac{3}{m} - \vartheta_j^{(k)^{\frac{qm}{3}}}\right)^{\acute{\upsilon}_k}\right)^{\frac{3}{qm}}, \left(\frac{3}{m} - \prod_{k=1}^{p}\left(\frac{3}{m} - \eta_j^{(k)^{\frac{qm}{3}}}\right)^{\acute{\upsilon}_k}\right)^{\frac{3}{qm}} \right\rangle$$
$$(j = 1, 2, .., n), \tag{11}$$

where $\varrho_j = \langle \zeta_j, \vartheta_j, \eta_j \rangle$.

Step 5. The score function given in Eq. (8) is utilized to render the crisp importance values of criteria ($S(\varrho_j)$).

Step 6. Criteria are prioritized in descending order on the basis of $S(\varrho_j)$ value, where s_j denotes the ranking positions of criteria. Consequently, the most crucial criterion is displayed as s_1.

Step 7. Comparative significance value for each criterion (c_j) is obtained by calculating the difference between the score of the first crucial criterion and the score of the second significant criterion in the pairwise comparison according to the criteria rankings.

Step 8. Values of k_j for each criterion are calculated with the help of Eq. (12):

$$k_j = \begin{cases} 1, & \text{if} s_j = s_1, \\ c_j + 1, & \text{if} s_j \neq s_1. \end{cases} \tag{12}$$

Step 9. Values of q_j for each criterion are obtained through Eq. (13):

$$q_j = \begin{cases} 1, & \text{if} s_j = s_1, \\ \frac{q_{j-1}}{k_j}, & \text{if} s_j \neq s_1. \end{cases} \tag{13}$$

Step 10. Weight coefficients of the criteria are attained through Eq. (14):

$$w_j = \frac{q_j}{\sum_{j=1}^{n} q_j}, \tag{14}$$

where $w_j \geq 0$ and $\sum_{j=1}^{n} w_j = 1$.

3.4 Identifying the sustainability performance of the freight mode options

The steps for implementing the MGqNS-ARAS are given below:

Table 4 Linguistic terms to assess the criteria and options

Linguistic terms for importance levels of criteria	Linguistic terms for options	NN $\langle \zeta, \vartheta, \eta \rangle$
Extremely High Importance (EHI)	Extremely Good (EG)	$<1, 0, 0>$
Very Very High Importance (VVH)	Very Very Good (VVG)	$<0.9, 0.1, 0.1>$
Very High Importance (VHI)	Very Good (VG)	$<0.8, 0.15, 0.2>$
High Importance (HI)	Good (G)	$<0.7, 0.25, 0.3>$
Above Average Importance (AAI)	Medium Good (MG)	$<0.6, 0.35, 0.4>$
Average Importance (AI)	Fair (F)	$<0.5, 0.5, 0.5>$
Below Average Importance (BAI)	Medium Low (ML)	$<0.4, 0.65, 0.6>$
Low Importance (LI)	Low (L)	$<0.3, 0.75, 0.7>$
Very Low Importance (VLI)	Very Low (VL)	$<0.2, 0.85, 0.8>$
Very Very Low Importance (VVL)	Very Very Low (VVL)	$<0.1, 0.9, 0.9>$
Extremely Low Importance (ELI)	Extremely Low (EL)	$<0, 1, 1>$

Step 1. Experts appraise the options using the linguistic terms in Table 4. Here, $\Omega = \left[l_{ij}^{(k)}\right]_{m \times n}$ is the linguistic decision matrix for the kth expert, where $(i = 1, \ldots, m)$ are the options, $(j = 1, \ldots, n)$ the criteria, and $(k = 1, \ldots, p)$ the experts. Then, $X^{(k)} = \left[x_{ij}^{(k)}\right]_{m \times n}$ is formed for each expert using NNs, where $x_{ij}^{(k)} = (t_{ij}^{(k)}, b_{ij}^{(k)}, f_{ij}^{(k)})$ (Aytekin et al. 2022; Turskis et al. 2022).

Step 2. Weights for the experts' assessments are computed as discussed in Step 2 of MGqNS-SWARA. Moreover, the weight coefficients for the criteria are determined. In this work, the MGqNS-SWARA method was utilized to obtain the w_j values.

Step 3. Experts' evaluations are integrated using mGqNWGA as seen in Eq. (15):

$$x_{ij} = \left\langle \prod_{k=1}^{p} t_{ij}^{(k)^{\acute{\upsilon}_k}}, \left(\frac{3}{m} - \prod_{k=1}^{p} \left(\frac{3}{m} - b_{ij}^{(k)^{\frac{qm}{3}}} \right)^{\acute{\upsilon}_k} \right)^{\frac{3}{qm}}, \left(\frac{3}{m} - \prod_{k=1}^{p} \left(\frac{3}{m} - f_{ij}^{(k)^{\frac{qm}{3}}} \right)^{\acute{\upsilon}_k} \right)^{\frac{3}{qm}} \right\rangle$$
$$(i = 1, 2, \ldots, m; j = 1, 2, ..., n), \tag{15}$$

where $x_{ij} = (t_{ij}, b_{ij}, f_{ij})$.

Step 4. An artificial optimal alternative is created based on the best values in each criterion in the integrated decision matrix X using Eq. (16), where J_b denotes benefit criteria, while J_c shows cost criteria:

$$z_{0j} = \begin{cases} \left\langle \max\limits_{i} t_{ij}, \min\limits_{i} t_{ij}, \min\limits_{i} t_{ij} \right\rangle, & \text{if } j \in J_b, \\ \left\langle \min\limits_{i} t_{ij}, \max\limits_{i} t_{ij}, \max\limits_{i} t_{ij} \right\rangle, & \text{if } j \in J_c. \end{cases} \tag{16}$$

In this context, the artificial optimal alternative is added to X, and the improved decision matrix Z is constructed, as seen in Eq. (17) (Liu & Cheng 2019; Zavadskas & Turskis 2010):

$$Z = \begin{bmatrix} z_{01} & \cdots & z_{0j} & \cdots & z_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ z_{i1} & \cdots & z_{ij} & \cdots & z_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ z_{m1} & \cdots & z_{mj} & \cdots & z_{mn} \end{bmatrix}, \quad (17)$$

where $z_{ij} = (t_{ij}, b_{ij}, f_{ij})$.

Step 5. The decision matrix is normalized through Eq. (18), where J_b denotes benefit criteria, while J_c shows cost criteria:

$$r_{ij} = \begin{cases} \langle t_{ij}, b_{ij}, f_{ij} \rangle, & \text{if } j \in J_b, \\ \langle f_{ij}, 1 - b_{ij}, t_{ij} \rangle, & \text{if } j \in J_c. \end{cases} \quad (18)$$

Step 6. Optimality function values are computed using Eq. (19) (Zavadskas & Turskis 2010):

$$Q_i = \sum_{j=1}^{n} w_j r_{ij}. \quad (19)$$

Step 7. Utility degrees of the options are obtained using Eq. (20), where $S(Q_i)$ stands for the score value of Q_i for the i^{th} alternative, while $S(Q_0)$ shows the score value of Q_0 for the optimal alternative (Zavadskas & Turskis 2010):

$$K_i = \frac{S(Q_i)}{S(Q_0)}. \quad (20)$$

The options are prioritized in descending order on the basis of the K_i values (Zavadskas & Turskis 2010).

4 Results and discussion

Here, the impacts of freight transport mode and route selection on the freight transport industry's sustainability performance are examined using the suggested model. The followed basic procedure of the suggested model is illustrated in Fig. 1.

We identified a case study to investigate and demonstrate the robustness and practicality of the model. A routine freight transport operation conducted for carrying textile products from Bursa to Frankfurt is selected as a case study to represent the effectiveness and reliability of the suggested approach. This case study is approved to quite fit by experts and researchers concerning the main focal point of the study, as over 11,000 freight transport operations (UND 2022) are carried out to carry various types of products between Turkey and Germany. In addition, over 400 thousand expeditions are performed from Turkey to EU countries annually (TCMB 2022), and freight transport companies use these routes to export various products and materials. We set 11 alternative routes, including unimodal freight transport options, such as road, rail, and maritime transportation, and multimodal transport variants, such as intermodal and combined transportation between cities.

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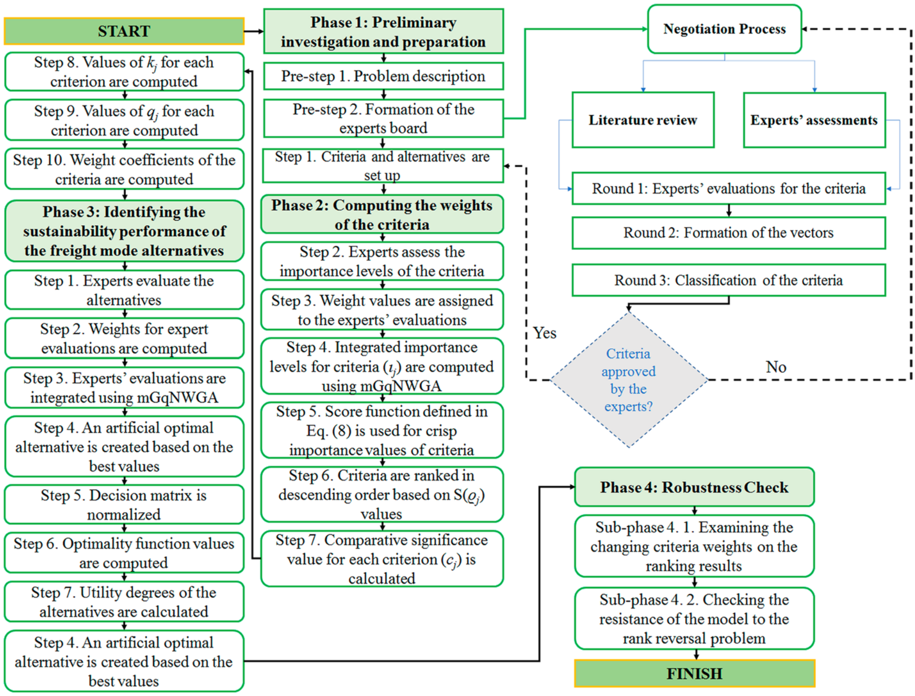

Fig. 1 Framework of the suggested model

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Next, we identified criteria by applying the Delphi techniques extended with the help of NSs. Afterwards, we evaluated the sustainability performances of each transport mode with the help of the proposed integrated decision-making model. We identified the best freight transport route options by considering the sustainability performance of each mode. The main procedure of the model to assess the sustainability performance of freight transport modes has been followed. The results obtained by following the offered model's execution steps are given below.

4.1 Preliminary investigation

First, a set of research questions is identified by researchers to structure the research process correctly, as shown in the preceding section. Next, we decided to construct a working team to acquire more technical and detailed information and evaluation concerning the

Table 5 Detailed information about the experts

DMs	Exp	Graduate	Degree	Duty	Role in Association
DM1	23	Economics	Master Degree	General Manager	Vice President
DM2	22	Mechanical Engineering	Bachelor Degree	Operation Manager	Executive Committee Member
DM3	24	Business Management	Bachelor Degree	Operation Manager	Full Member
DM4	32	Public Finance	Bachelor Degree	Member of Board	Full Member
DM5	18	Mechanical Engineering	Master Degree	Company Owner	Vice President
DM6	20	Business Management	Master Degree	Company Owner	Member of the Supervisory Council
DM7	19	Industrial Engineering	Bachelor Degree	General Manager	Vice President

freight transport industry. For this purpose, we invited experts who are professionals as senior executives in the freight transportation industry for at least 15 years and are executive board members of an association, such as in international freight transportation, freight forwarding, and logistics. We decided to work with eight experts at the end of the negotiation process with these professionals. Nevertheless, one of them stated that he asked to be relieved from his duty because of his health problem, and we had to continue with seven professionals. Information and details about these experts are given in Table 5.

Next, several meetings with the experts were organized during the research process. The Delphi technique can be used to collaborate with a large or small group of experts. It is recommended that the Delphi technique must be utilized with at least seven experts (Aytekin 2022; Şahin 2021). However, there is little empirical evidence that the number of participants affects the reliability or validity of assessment processes in a Delphi study. If the sample size of a Delphi study is limited, these subjects may not be regarded to provide a representative pool of judgments on the subject. When the sample size becomes huge, drawbacks associated with the Delphi method may manifest, including the potential for low response rates and the need for extended time commitments from both respondents and researchers.

Delphi does not require expert panels to be statistically representative samples. The merits of the expert panel, not its size, are considered to determine representation (Hsu and Sandford 2007; Powell 2003). In this context, the Delphi technique requires carefully selecting panel members. Panel members should be able to provide a profound understanding of the studied subject due to their expertise and qualifications, and they should have robust views on the subject. Due to the smallness of the expert pool on the studied subject and the availability of experts who might reflect the views on the problem, seven expert opinions were accepted as sufficient in this study. In the first meeting, we presented the main aims of the research process and the steps that will be followed. Furthermore, we gave information about our expectations of them and their duties and responsibilities. Finally, we concluded the first meeting after noting their opinion and suggestions.

4.2 Identifying the criteria by using mathematical frameworks

Until the next meeting, we performed an extensive literature review to determine the criteria used in previous works dealing with the sustainability of freight transport using decision-making frameworks. We listed all 256 criteria addressed in the previous studies without any elimination.

In the first round of the evaluation process, we discussed these criteria. We eliminated some criteria irrelevant to freight transport sustainability according to the experts' overall view. At the end of the first round, 99 criteria remained to evaluate with the help of the NN-Delphi technique (see Table A in Supplementary Materials). Performing the linguistic evaluations was adjourned to the next round, as the first round took too long due to long-lasting negotiations. In the second round (organized one month later), each expert performed linguistic assessments for each criterion by considering the linguistic evaluation scale. These linguistics evaluations are presented in Table B (Supplementary Materials). Then, we collected these evaluations and computed the preference score of each criterion by applying the proposed approach. Next, we classified these criteria into three groups concerning preference scores by considering the limit score value presented in Table B (Supplementary Materials). Finally, we set 42 criteria to assess the impacts of freight transport modes and routes on the sustainability performance of freight transportation. Besides, these criteria were grouped as economic, environmental, social, and operational. Table F (Supplementary Materials) represents the research criteria and their features.

After identifying the criteria, we discussed the route and mode variants with the experts. First, available freight transport modes used by freight transport companies between Turkey and EU countries are selected. Next, we evaluated possible transport routes even though they are currently unavailable. Table 6 demonstrates these transport routes and modes of freight transport.

In the third and final round of the process, the criteria and options were presented to the experts to take their opinions, and the experts approved the criteria and options with complete consensus. Finally, we decided to assess only freight transport modes' sustainability performances and to identify the best route alternative by considering the preference ratings of the mode options. In addition, we decided to include airway transportation, though it is not a freight transport mode for this operation. Next, we collected linguistics appraisals from the experts for criteria and options. We computed the criteria weights and evaluated the sustainability performance of the freight transport modes in the following sections.

4.3 Computing the criteria weights

Table C (Supplementary Materials) contains expert evaluations used in the criteria' weighting procedure. The expert evaluations of the solutions were assigned equal weight. The problem is also solved by setting $m = 1$ and $q = 2$. Table 7 shows the criteria weight values obtained using MGqNS-SWARA.

According to Table 7, the most important criterion is "Cargo Security." Moreover, "Accident rates", "Logistics Skill", "Efficiency", "Safety and Security", "Logistics Infrastructure", "Cost of Energy", "Visual intrusion", "Complexity in Planning", and "Corruption" are the first ten critical criteria. When the main criteria groups are examined, the economic dimension group has the highest weight with 0.325, and the operational dimension group has the second highest weight with 0.322. The weight of the third most crucial leading criterion group, the social dimension group, is 0.236, while the weight of the minor essential criterion group is 0.117.

Table 6 Freight transport modes, groups, and route variants

Transportation modes for freight transport operations

Options	Modes	Definitions
A1	Road	Transportation mode for carriage freights on roadways using wheel-based road vehicles
A2	Maritime	Transportation mode to transport freight via sea routes
A3	Airway	Transportation type to transport freight by using planes
A4	Railway	Conveyance of freight using rail tracks
A5	Intermodal	Movement of goods using transport systems combinations involving at least two or more transport modes without handling operations
A6	Combined	Transport mode involving carriage goods with loading units on transport modes, such as maritime or railway over long-distance

Main transportation group involving different transport modes

Main groups	Definitions
P1	Routes for unimodal (roadway) freight transport
P2	Routes with combinations of road and railway transport
P3	Routes with combinations of road, maritime, and railway transport
P4	Routes with combinations of road and maritime transport

Alternative routes

Main	Code	Routes
P1	Q1	Bursa-Istanbul-Bulgaria-Romania (Free)-Hungary (Free)-Austria-Germany
P1	Q2	Bursa-Istanbul-Bulgaria-Romania (Free)-Hungary (Toll)-Austria -Germany
P1	Q3	Bursa-Istanbul-Bulgaria-Romania (Hourly)-Hungary (Toll)-Austria -Germany
P1	Q4	Bursa-Istanbul-Bulgaria-Serbia-Hungary (Free)-Austria-Germany

Table 6 (continued)

Alternative routes		
Main	Code	Routes
P1	Q5	Bursa-Istanbul-Bulgaria-Serbia-Croatia-Slovenia-Austria-Germany
P2	Q6	Bursa-Istanbul-Bulgaria-Romania (Free)-Szeged- Wels train-Austria- Germany
P2	Q7	Bursa-Istanbul-Bulgaria-Serbia-Szeged-Wels train-Austria-Germany
P2	Q8	Bursa-Istanbul-Bulgaria-Serbia- Croatia-Slovenia-Maribor-Wels -Austria-Germany
P3	Q9	Bursa-İzmir-Çeşme-Trieste Ro-Ro-Trieste-Salzburg train-Austria-Germany
P3	Q10	Bursa-Istanbul-Pendik-Trieste Ro-Ro-Trieste-Salzburg train-Austria-Germany
P4	Q11	Bursa-İzmir-Çeşme-Trieste Ro-Ro -Austria -Germany
P4	Q12	Bursa-Istanbul-Pendik-Trieste Ro-Ro-Austria -Germany

Table 7 Results obtained from the application of MGqNS-SWARA

Criteria	$S(\varrho_j)$	s_j	c_j	k_j	q_j	w_j	Criteria	$S(\varrho_j)$	s_j	c_j	k_j	q_j	w_j
C21	0.9107	1	–	1.0000	1.0000	0.0276	C18	0.7582	22	0.0005	1.0005	0.8595	0.0237
C36	0.8832	2	0.0275	1.0275	0.9732	0.0269	C2	0.7568	23	0.0014	1.0014	0.8583	0.0237
C34	0.8717	3	0.0115	1.0115	0.9621	0.0266	C30	0.7540	24	0.0028	1.0028	0.8558	0.0236
C7	0.8695	4	0.0021	1.0021	0.9601	0.0265	C33	0.7467	25	0.0073	1.0073	0.8496	0.0235
C19	0.8695	4	0.0000	1.0000	0.9601	0.0265	C35	0.7467	26	0.0000	1.0000	0.8496	0.0235
C23	0.8695	4	0.0000	1.0000	0.9601	0.0265	C13	0.7453	27	0.0013	1.0013	0.8485	0.0234
C1	0.8692	7	0.0003	1.0003	0.9598	0.0265	C42	0.7425	28	0.0028	1.0028	0.8461	0.0234
C22	0.8562	8	0.0130	1.0130	0.9475	0.0262	C37	0.7361	29	0.0065	1.0065	0.8407	0.0232
C32	0.8430	9	0.0132	1.0132	0.9351	0.0258	C8	0.7307	30	0.0053	1.0053	0.8363	0.0231
C41	0.8413	10	0.0017	1.0017	0.9336	0.0258	C28	0.7295	31	0.0012	1.0012	0.8352	0.0231
C26	0.8301	11	0.0113	1.0113	0.9232	0.0255	C5	0.7070	32	0.0225	1.0225	0.8168	0.0225
C29	0.8155	12	0.0146	1.0146	0.9099	0.0251	C17	0.6974	33	0.0095	1.0095	0.8091	0.0223
C20	0.8155	13	0.0000	1.0000	0.9099	0.0251	C27	0.6938	34	0.0036	1.0036	0.8062	0.0223
C10	0.8107	14	0.0048	1.0048	0.9056	0.0250	C38	0.6631	35	0.0307	1.0307	0.7822	0.0216
C25	0.7995	15	0.0112	1.0112	0.8956	0.0247	C39	0.6359	36	0.0272	1.0272	0.7615	0.0210
C6	0.7856	16	0.0140	1.0140	0.8832	0.0244	C3	0.6231	37	0.0128	1.0128	0.7519	0.0208
C31	0.7815	17	0.0040	1.0040	0.8797	0.0243	C11	0.6231	38	0.0000	1.0000	0.7519	0.0208
C15	0.7699	18	0.0116	1.0116	0.8696	0.0240	C16	0.6170	39	0.0061	1.0061	0.7473	0.0206
C14	0.7674	19	0.0025	1.0025	0.8674	0.0239	C40	0.6137	40	0.0033	1.0033	0.7448	0.0206
C9	0.7601	20	0.0073	1.0073	0.8611	0.0238	C4	0.5616	41	0.0520	1.0520	0.7079	0.0195
C24	0.7587	21	0.0014	1.0014	0.8599	0.0237	C12	0.5616	42	0.0000	1.0000	0.7079	0.0195

Table 8 Results obtained from the application of MGqNS-ARAS

Options	Q_i	$S(Q_i)$	K_i	Ranking
A1	(0.5998, 0.4009, 0.4071)	0.5987	0.7659	2
A2	(0.5091, 0.4955, 0.4896)	0.5078	0.6497	6
A3	(0.5935, 0.4300, 0.4328)	0.5833	0.7463	3
A4	(0.5938, 0.4214, 0.0000)	0.6171	0.7895	1
A5	(0.5400, 0.4482, 0.4472)	0.5455	0.6979	4
A6	(0.5359, 0.4599, 0.4613)	0.5376	0.6878	5
Optimal	(0.7688, 0.2044, 0.0000)	0.7816	1.0000	–

4.4 Computing the preference ratings of options

Table D (Supplementary Materials) includes expert evaluations employed in the rating procedure of the options. The problem is also solved by setting $m = 1$ and $q = 2$. Besides, Table E (Supplementary Materials) displays the integrated decision matrix. In this context, Table 8 displays the results obtained using MGqNS-ARAS. Variants are ranked as A4≻A1≻A3≻A5≻A6≻A2. Accordingly, the best choice is the Railway mode.

4.5 Robustness evaluation

Here, we verified the proposed mathematical tool's robustness and applicability by conducting an exhaustive sensitivity analysis involving two phases. In the first phase, we modified each criterion weight to investigate the effects of changing criteria weights on the overall outcomes. For this purpose, the approach offered by Görçün et al. (2021) and Zolfani et al. (2022) is considered. In this phase, starting with the most notable criterion, each criterion's weight was altered from 10 to 100%. The difference value was uniformly incorporated into the weights of the remaining criteria to render the main condition that the sum of the criteria weights should equal 1. In this study, we formed 420 scenarios by following the basic algorithm. The mathematical expressions of the following algorithm are displayed below:

$$w_{fv}^1 = w_{pv}^1 - \left(w_{pv}^1 m_v\right), \tag{24}$$

$$w_{nv}^2 = \frac{\left(1 - w_{fv}^1\right)}{n - 1} + w_{pv}^2, \tag{25}$$

$$w_{fv}^1 + \sum w_{nv}^2 = 1, \tag{26}$$

where w_{fv}^1 displays the new value of the altered weight of the j^{th} factor, w_{pv}^1 is the previous value of the criterion and m_v shows the alteration degree in terms of percentage (i.e., 10%, 20%,…,100%). Here, w_{nv}^2 and w_{pv}^2 stand for new values of remaining factors and the previous value of the remaining criteria, respectively. Moreover,n stands for the number of factors.

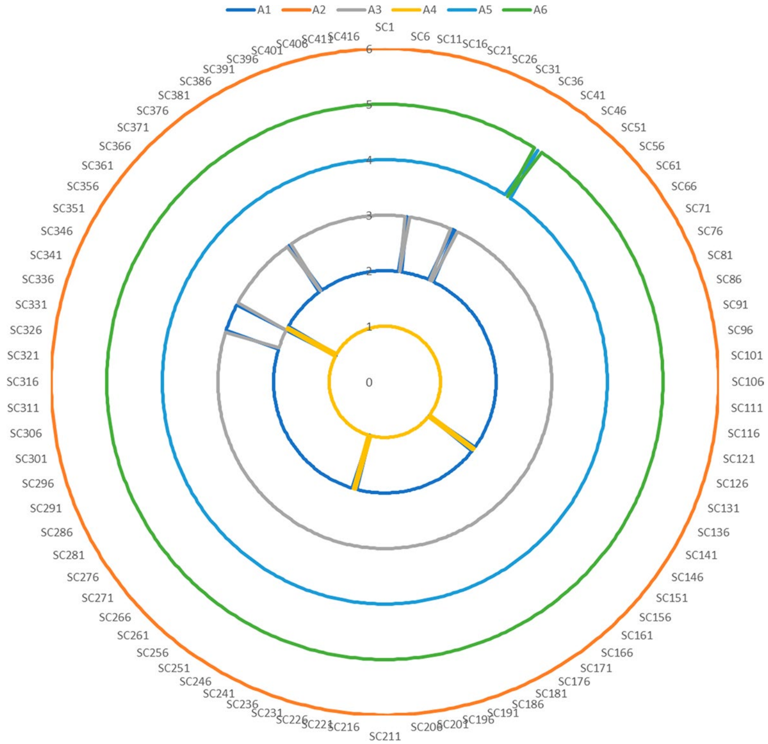

Fig. 2 Re-ranking the options concerning the changing criteria weights

Table 9 Assessment of the changes in the ranking results

Options	Criteria							
	C1	C2	C3	C14	C22	C33	C34	C37
A1	> %100	> %90		> %90	> %90	> %70	All	> %100
A2	None							
A3	> %100	> %90				> %70	All	> %100
A4				> %90	> %90		> %90	
A5			> %100					
A6			> %100					

As shown in Fig. 2, the C34 "public support" is a very sensitive factor, and any change in this criterion can lead to fluctuations in the ranking performances of options A1 and A3. However, it causes the ranking position of alternative A4, the best alternative, when its weight is changed by over 90%, which can be accepted as an excessive modification. The same condition is observed for C22 and C14 criteria. Both criteria have caused fluctuations in the ranking performances of options A1 and A4 when the weights of both criteria change by over 90%.

The results of changing the ranking performances depending on the modification of the criteria weights are presented in Table 9.

Furthermore, the average similarity ratio was calculated as 0.9817, a value that can be accepted as very high. The suggested model is broadly consistent and stable according to the results acquired in the first phase of the sensitivity analysis. Although minor fluctuations in the ranking performance of the options were noted, the overall results cannot change. Besides, changes in the ranking of the options occurred when the criteria weights excessively changed, which cannot be faced in real-life conditions. Any criterion's weight equals zero or changed over 90%, which is not normal. No change has been noticed when the criteria weights changed under this ratio. Thus, the maximum limit for some criteria (e.g., C1, C2, C3, C14, C22, C33, C34, and C37) is identified under 90%. Besides, no change has been observed when the weights of the remaining criteria were changed. Hence, it can be indicated that the developed model is maximally trustworthy for DMs, as there are no critical and severe fluctuations in the overall ranking results despite excessive modifications of criteria weights.

In the next stage of the sensitivity analysis, we check the resistance of the proposed mathematical tool to the rank reversal problem. Consequently, we eliminated the worst alternative in each scenario and repeated the calculations for the remaining variants. Therefore, testing the solution using the proposed ARAS method was initially checked to remove the variants from the problem individually. In this context, the changes in the ranks of the existing variants were investigated and outlined in Table 9. The results in Table 10 reveal that the ARAS method has no rank reversal problem in removing the variants.

5 Theoretical and practical implications

In today's extremely competitive climate, it is becoming increasingly difficult for businesses to sustain themselves with financial success from selling goods and services. Businesses are evaluated on their financial success and the environmental and social consequences of their operations and transactions. Individuals become intellectually aware of sustainability as their unsustainable activities are revealed and documented. Furthermore, many daily activities of managers, board members, auditors, employees, and non-governmental organizations and their positive/negative actions on social and environmental issues shape sustainability (Benn et al. 2014). The need for transportation increased because of globalization and economic growth, particularly between 1970 and 2000. At this point, there was a need for short-term planning and improvements to the transportation system's productivity and efficiency. It has been one of the most effective strategies in managing and planning freight transportation logistics chains to meet this need (Meersman and van de Voorde 2019). In this context, the evaluation of the findings obtained provides many benefits. An essential part of this discussion is comparing the findings to the literature and highlighting the similarities and differences.

When we examine the final weights of the sustainable freight transportation criteria represented in Table 7, "Cargo Security" has been identified as the most crucial criterion. The result obtained is consistent with that of the studies of Lányi (2018), and Ahmady and Eftekhari Yeghaneh (2022). Cargo security, for example, can be viewed as both a cost-cutting measure and a function that improves internal and external customer satisfaction. Because in terms of sustainable freight transportation, cargo security is a remedial function that

Table 10 Robustness measurement based on removing variants from the problem

Variants	Set 1			Set 2			Set 3			Set 4		
	$S(Q_i)$	K_i	Ranking	$S(Q_i)$	K_i	Ranking	$S(Q_i)$	K_i	Ranking	$S(Q_i)$	K_i	Ranking
A1	–	–	–	–	–	–	–	–	–	–	–	–
A2	0.5078	0.7037	5	–	–	–	–	–	–	–	–	–
A3	0.5833	0.8083	2	–	0.8174	2	–	–	–	–	–	–
A4	0.6171	0.8551	1	0.6171	0.8648	1	0.6171	0.9043	1	–	–	–
A5	0.5455	0.7559	3	0.5455	0.7644	3	0.5455	0.7994	2	0.5455	0.9271	1
A6	0.5376	0.7450	4	0.5376	0.7534	4	0.5376	0.7879	3	0.5376	0.9137	2
Optimal	0.7216	1.0000		0.6824	1.0000		0.6824	1.0000		0.5884	1.0000	

increases demand while directly impacting the capacity utilization rate. Furthermore, customer satisfaction will rise due to the implementation of measures to ensure and strengthen cargo security. It may appear that establishing cargo security measures is a simple task, but what is tough and required is the supply and control of the financial resources required to maintain the identified security measures effectively.

"Accident rates" were identified as the second most important criterion. The findings are similar to those of Ližbetin & Stopková (2021) and Korucuk (2021). This criterion may be considered crucial in freight transportation, especially given Turkey's existing geographical location, traffic circumstances, personnel status, and population. On the other hand, when considering retail purchasing opportunities, carrying capacity, warehouse space usage, and environmental consequences, traffic accidents play a significant role in sustainable freight transportation. Traffic safety is a critical problem in the prevention of traffic accidents. Traffic safety, crucial for individual and social considerations, has become part of the safety culture. Ensuring the safety of people and property and preventing accidents, injuries, and fatalities depend heavily on traffic safety. In order to avoid and prevent traffic accidents in the freight transportation sector, there is a higher demand for practices and laws.

As a result of the research, "Logistics Skills" has been identified as another crucial factor in sustainable freight transport. The results supported the literature findings (Askariazad and Wanous 2009; Shankar et al. 2018; Korucuk 2016; Choudhury et al. 2021). Three criteria are used to evaluate a logistics capability: coordination, innovation, and customer relations (Kallio et al. 2012). It is based on providing semi-finished products or raw materials and carrying out production and marketing tasks, including stock management, physical distribution, and stakeholder cooperation and coordination, which are necessary for sustainable freight transportation. With the ability to innovate in this area, developing a logistics capability that will be very challenging for rivals to imitate is possible. Effective customer relationship management and competitive power all contribute to greater satisfaction.

The findings regarding the importance of the main criteria, economic, social, environmental, and operational dimensions, can have significant implications for companies. Accordingly, companies must prioritize economic and operational factors for sustainable freight transportation. The trade-off between these criteria can vary as people, governments, and businesses become more sensitive to environmental concerns and social pressure. Consistent with prior research (Pathak et al. 2019; Kumar Dadsena et al. 2019; Kumar and Anbanandam 2020a, b, c; de Freitas et al. 2021), this study found that operational and economic aspects continue to be critical in mitigating the pressures of competitors and customers. Companies are reluctant to implement better environmental policies due to increased short-term costs. However, in order to ensure sustainable freight transportation for businesses, these aspects should be improved together rather than separately (Buldeo Rai et al. 2018; de Campos et al. 2019; Kumar and Anbanandam, 2019; Pathak et al. 2019; de Freitas et al. 2021). It is essential to reduce the costs associated with logistics, improve the supply chain's environmental performance, decrease the adverse effects on society by minimizing the likelihood of accidents and noise levels, and accomplish these goals by operating the business efficiently (Mrabti et al. 2020).

The most crucial main criterion is the economic dimension, formed primarily by transport costs, efficiency, and risk factors. International transportation businesses must conduct activities for efficiency, effectiveness, and high performance, particularly in sustainable transportation. Furthermore, unanticipated increases in transportation costs and risks can harm a company's financial performance, cash flows, profitability, and, as a result, market value. Therefore, correctly recognizing and managing transportation costs and risks, which are significant factors in international transportation, favours businesses when making international strategic decisions and contributes to their competitiveness.

It can be seen that the operational dimension, which is another essential main criterion, is dependent on sub-criteria such as quality, flexibility, logistics infrastructure, technology, and management. The ability to respond promptly to changing market conditions and provide the appropriate service level in sustainable transportation metrics significantly strengthens the hand of transportation businesses. One of the critical aspects influencing the integrated evaluation of managerial factors and business profitability is the execution of an integrated service structure with a quick response to targeted demand. Furthermore, developing an effective, sustainable transportation cargo security system is one factor that plays an active role in creating and implementing sustainable transportation in both local and international markets.

The sub-criteria that constitute the social aspect main criterion include a variety of factors such as personnel training, injuries, corruption, and public support. The effective management of logistics skills by experienced staff, particularly, has a favourable impact on sustainable transportation and decreases accident and injury levels. Finally, the environmental dimension, the main criterion with the lowest importance level, includes sub-criteria such as noise level, air pollution, government regulations, and green practices. The major components that concern all businesses and society are regulations and implementing environmentally friendly practices to enhance sustainable transportation.

Furthermore, the results showed that "Railway" was the best alternative. This finding is in accord with what was found by Hao and Yue (2016) and Kurenkov et al. (2019)—for the combination of land and sea transportation routes in sustainable freight transportation, using "Railway" as the best alternative is essential. It provides cost advantages to its users and flexibility in delivering the goods at the appropriate time and to the desired location when multimodal transportation difficulties are considered. Railway transportation also has advantages in terms of criteria for cargo security and accidents in sustainable freight transportation. By combining different modes of transportation, railway transportation enables the effective, efficient, and economical use of resources. Railway transportation also increases customer value and creates positive effects on service quality.

In addition, all members of the experts' group are representative of large-scale logistics firms in Turkey, and almost all logistics companies in Turkey mainly carry out their transportation activities from Turkey to EU countries by using road transportation mode (TCMB 2022; UND 2022). the share of railway transportation is approximately 0.77% of total exports (UTIKAD 2022). Nonetheless, the acquired outcomes confirm that the members of the board of experts are aware of the significance and critical role of railway transportation concerning sustainable freight transportation. Based on the experts' evaluations, field works, and detailed investigations, the paper's main finding points out that the availability and utilization of the railway transport system are essential in creating a sustainable freight transport system.

However, senior executives of logistics companies still rate road freight transportation above maritime, intermodal, and combined transportation concerning its economic advantages, though road freight transportation is mainly responsible for environmental pollution and transportation externalities. According to the assessments performed by these professionals, road freight transportation is the second-best option concerning the overall sustainability performance of freight transportation. Although this outcome may seem misleading with respect to environmental sustainability, it may be accurate when considering freight transportation's economic and social sustainability. Moreover, road transportation is an indispensable option for each freight transport route alternative, as each operation starts and finishes with the road transportation mode. Aside from door-to-door freight transport operations, road freight transport is a unique transport mode providing connection between door-to-port/railway station and port/railway station-to-door.

By considering the outcomes and findings of the paper concerning the sustainability performance of the freight transport mode variants, transport operators and freight forwarders can set the optimal freight transport route option. In this paper, railway transportation has been identified as the most sustainable freight transport mode, and unimodal or multimodal transport modes that do not use railway transport can be eliminated. The main route groups, P2 and P3, can be considered sustainable freight transport routes. In this work, we considered the share of railway transportation in total mileage from Bursa to Frankfurt. Hence, the Q7 alternative is the best option for freight forwarders, as 25% of the total distance can be travelled by railway. Furthermore, Q6 is the closest route alternative to the best option, and 23 of the total distance can be travelled with this route alternative. Others' value concerning the share of railway transportation is under 13%.

In addition, the acquired results show that intermodal and combined freight transport modes could not adequately have confidence concerning their positive effects and advantages for DMs in the logistics and transportation industry. Although intermodal and combined transport modes have many positive effects on the economy and environment (Kumar and Anbanandam 2020a; Pizzol 2019; Qu et al. 2016), representatives of the Turkish logistics industry think that the sustainability performance of both transport modes is not at a satisfactory level. Moreover, as maritime transportation is dependent mainly on fossil-based fuels, there are severe and noteworthy concerns about the environmental sustainability performance of the maritime industry in the relevant literature (Garg and Kashav 2019; Greene et al. 2020; Trivedi et al. 2021). There are a few effective research on alternative fuel usage in maritime transportation (Lindstad et al. 2021; Kołakowski et al. 2022) in the literature, but these studies could not have relieved concerns about the maritime transportation' environmental sustainability.

Besides, judgments of the senior executives of the Turkish logistics and transportation industry concerning the sustainability performance of the maritime transportation mode are also connected with the economic sustainability performance of this transport mode aside from its environmental sustainability performance. The acquired outcomes in the present work confirm that the industry does not find the overall sustainability performance of maritime transportation. These findings confirm concerns of the prior studies in the literature concerning the sustainability of maritime transportation. When it is evaluated in general, the main findings and outcomes of the paper relate to real-life conditions, and they are consistent and stable. It shows that the developed model can be executed to tackle enormously complicated decision-making problems in real-world conditions. In addition, the robustness and practicality of the suggested model have been validated with an extensive sensitivity analysis.

6 Conclusion and outlook

This work proposed a novel extension of the SWARA-ARAS combination based on mGqNSs to analyze the sustainability performance of the freight transport modes and identify more sustainable freight transport systems and routes. The proposed approach extensively evaluated the sustainability performance of the freight transport modes. It considered 42 sustainability criteria identified by applying the Delphi technique extended with the help of NSs. Thus, the study utilized a novel mathematical tool, the NN-Delphi approach, to set the sustainability criteria. It provided the opportunity to properly determine suitable criteria for structuring the decision problem.

Logistics and transportation industry practitioners can consider the study's findings as a roadmap to create a more sustainable freight transportation system. In addition, DMs can improve the available transportation systems (i.e., improving railway infrastructure) by considering the implications of the work. Furthermore, it presents several implications to the stakeholders concerning whether they should focus on and invest in freight transport modes in the future. Consequently, the model proposed in the present study is a critical and significant step to evaluate the mode variants and enhance the sustainability performance of the freight transportation disregarded in literature and practice. Lastly, it gives essential clues to set the sustainability strategies, which can help to increase the competition powers of their companies for senior executives of the logistics companies.

The originality and novelty of the study were to propose a pretty robust mathematical model to specify the relative weights of the criteria and sustainability performance of the variants aside from suggesting a novel mathematical tool to set the criteria influencing the sustainability performance of the freight transport modes. Therefore, this study served the purpose of three aims. First, it utilized a mathematical approach to determine the criteria logically by decreasing the effects of subjective and intuitionistic judgments of the practitioners. Secondly, it examined the significance and influences of the criteria. Thirdly, by evaluating the sustainability performance of freight transport modes, it associated the sustainability of freight transport modes and the freight transportation routes, modes, and combinations. Given this aspect, it provided the opportunity to create more sustainable freight transportation systems for the logistics and transportation industry DMs.

Although the current research work came up with precious theoretical contributions and managerial implications, it also has limitations. Undoubtedly, a single methodological framework cannot solve all decision problems. In this perspective, the methodology adopted in the current study has several limitations. Different fuzzy sets deal with uncertainty in different ways. The proposed methodological framework employs mGqNS, which provides a generalized and flexible structure of many fuzzy sets.

On the other hand, the proposed methodology fundamentally measures the uncertainty in the decision problem by memberships in truthfulness, indeterminacy, and falsity. In this framework, it is impossible to model all possible uncertainties and their aspects using a specific fuzzy or neutrosophic set. For example, the proposed methodology does not address bipolarity or the inclination to think in a bipolar manner. Another limitation is that the interval-valued neutrosophic evaluation is not included. Although evaluations were done by considering many scenarios in sensitivity analysis and comparisons, solutions were provided based on a subjective weighting technique and a ranking method. Because of the complexity of the problem and the importance placed on expert opinions in its solution, a subjective weighting technique was employed in this study. Employing the methodological framework produced in this study as a basis, an extension can be proposed in similar studies to find a compromise between the subjective and objective approaches by using an objective weighting technique that considers the data structure in the decision matrix. Different economic, social, environmental, and operational scenarios may need re-evaluation of the decision problem's criteria and alternative sets.

Furthermore, if the nature of the problem changes, the proposed methodological framework must be changed. However, a methodical framework for dealing with uncertainty and inaccurate data is provided. The proposed methodological framework can be employed to solve future sustainable freight transportation problems or similar problems in other fields, or it can be used as a basis for further research.

Specialists' experience and comprehensive knowledge play critical roles in the transport industry concerning route and mode selection, as the international freight transportation industry has an extraordinarily dynamic structure, and complex uncertainties and easily variable situations exist in the relevant industry. Hence, selecting DMs is a critical and sensitive issue, and not being adequately careful when selecting experts may lead to distortions in the final results. Besides, some factors concerning special freight transport operations, such as the transportation of dangerous goods and the transportation of frozen and chilled foods, have not been considered in this study. Moreover, the present study has geographical limitations, as the DMs, who are the working group members, are the representatives of the Turkish logistics and transportation industry. Though this industry is an internationalized sector, assessments of DMs in different regions or countries may vary. In addition, a freight transport operation from Turkey to Germany was chosen as a case study, and the acquired outcomes for freight transport routes and available transport modes between these countries may not be generalized for freight transport routes between different countries (i.e., from Turkey to Spain or France). The researchers and authors can evaluate the sustainability performance of freight transport modes for special freight transport operations in the subsequent research. Furthermore, this study can be repeated for various regions and countries to compare obtained outcomes. It is also possible to work with more experts from various countries and assessments of professionals from various industries concerning the sustainability of the freight transport modes can be compared with the evaluations of the experts in the freight transport industry.

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Declarations

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