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Abstract

Purpose - The oil and gas industry is a crucial economic sector to both developed and developing economies. Delays in extraction and refining of these resources would adversely affect industrial players including that of the host countries. Supplier selection is one of the most important decisions taken by managers of this industry that affect their supply chain operations. However, determining suitable suppliers to work with has become a phenomenon faced by these managers and their organizations. Furthermore, identifying relevant, critical and important criteria needed to guide these managers and their organizations for supplier selection decisions has become even more complicated due to various criteria that need to be taken into consideration. With limited works in the current literature of supplier selection in the oil and gas industry having major methodological drawbacks, this paper attempts to develop an integrated approach for supplier selection in the oil and gas industry.

Design/Methodology/Approach - To address this problem, this paper proposes a new uncertain decision framework. A grey-Delphi approach is first applied to aid in the evaluation and refinement of these various available criteria to obtain the most important and relevant criteria for the oil and gas industry. The grey systems theoretic concept is adopted to address the subjectivity and uncertainty in human judgments. The grey-Shannon Entropy approach is employed to determine the criteria weights, and finally, the grey-EDAS (Evaluation based on Distance from Average Solution) method is utilized for determining the ranking of the suppliers.

Findings - To exemplify the applicability and robustness of the proposed approach, this study uses the oil and gas industry of Iran as a case in point. From the literature review, 21 criteria were established and using the grey-Delphi approach, 16 were finally considered. The four top-ranked criteria, using grey-Shannon Entropy, include warranty level and experience time, relationship closeness, supplier's technical level, and risks which are considered as the most critical and influential criteria for supplier evaluation in the Iranian oil and gas industry. The ranking of the suppliers is obtained, and the best and worst suppliers are also identified. Sensitivity analysis indicates that the results using the proposed methodology are robust.

Research limitations/implications - The proposed approach would assist supply chain practicing managers including purchasing managers, procurement managers and supply chain managers in the oil and gas and other industries to effectively select suitable suppliers for cooperation. It can also be used for supplier selection problems in other industries. It can also be used for other multi-criteria decision-making (MCDM) applications. Future works on applying other MCDM methods and comparing them with the results of this study can be addressed. Finally, broader and more empirical works are required in the oil and gas industry.

Originality/value - This study is among the first few studies of supplier selection in the oil and gas industry from an emerging economy perspective and sets the stage for future research. The proposed integrated grey-based MCDM approach provides robust results in supplier evaluation and can be used for future domain applications.

Keywords: Supplier selection; Multi-Criteria Decision Making; Evaluation Based on Distance from Average Solution; Grey Shannon entropy; Grey data; Oil and Gas industry.

1. Introduction

Over the past decade, supply chain management (SCM) issues and related works have received high priority in both academic and business environments (Yazdani et al., 2017). This is obvious from the increasing trend of SCM works in the literature as well as the number of literature reviews (e.g., Burgess et al., 2006; Seuring and Gold, 2012; Das and Jharkharia, 2018) in practically all diverse and emerging areas of SCM, mainly related to risk (Colicchia and Strozzi, 2012; Ho et al., 2015), sustainability (Gold et al., 2010; Seuring, 2013; Brandenburg et al., 2014), health services (De Vries and Robbert Huijsman, 2011), blood products (Beliën and Forcé, 2012), fresh produce products (Shukla and Jharkharia, 2013), computing applications (Ko et al., 2010), and performance measurement (Gopal and Thakkar, 2012). This trend shows that the number of works has increased dramatically over the recent decade. SCM encompasses various business activities which include purchasing, designing, manufacturing, production, among others, and these elements are becoming the focal areas of many domain SCM scholars. One such important area in SCM, both in theory and in practice, is supplier selection.

On the one hand, as opposed to the traditional cost criterion of selecting suppliers, supplier selection in modern competitive environments has been shifted to a multi-criteria decision-making (MCDM) problem involving conflicting and competing choices (trade-offs) (De Boer et al., 2001). For instance, a supplier may offer a low-quality product with a better and reliable delivery time while another may offer an uncertain delivery time with a high-quality product, setting up trade-offs for decision-makers. Selecting the right suppliers creates a strategic opportunity to improve organizational performance while failure to do so may cause negative repercussions on the firm (Dweiri et al., 2016). On the other hand, investigating the recent trends of MCDM methods demonstrates that uncertainty has been considered as an integral part of the decision-making process. There are several efficient logics involved in MCDM methods to handle imprecise information. Later studies in which fuzzy set theory (Zeng et al., 2018a; Zeng et al., 2018b), grey systems theory (Çelikbilek, 2018), Dempster–Shafer Evidence Theory (Chen & Deng, 2018a; Chen & Deng, 2018b), combination of fuzzy and grey logics (Wang et al., 2018), combination of rough and fuzzy sets (Pamučar et al., 2018) and similar approaches have been utilized in MCDM methods, all demonstrate that employing uncertain MCDM methods is increasing to modeling the inherent uncertainty in diverse decision-making problems.

The attention related to the content and the implementation of the supplier selection process has been at the forefront of discussions among scholars in the current literature. As such, it is even more heightened by the several issues, and pressures decision-makers are facing in today's competitive environment. Supplier selection studies in various industries have been reported in the literature such as Büyüközkan & Çifçi (2011); Liao & Kao (2010); Asgari et al., (2016); Wang and Cai, (2017); Fei et al., (2018); and Jain et al., (2018). Note that this list is not intended to be comprehensive. Due to its crucial role in SCM and to hundreds of articles published in this domain, a number of review papers have been reported in the current literature along with some crisscrossing topics; for instance, an extensive review within 1991-2011 (Ware et al., 2012), the emphasis on the methodology (De Boer et al., 2001; Bhutta, 2003), decision-making techniques (Chai, Liu, and Ngai, 2013), MCDM techniques (Ho, Xu, and Dey, 2010; Agarwal et al., 2011; Govindan, Rajendran, Sarkis, and Murugesan, 2015), criteria and methods (Deshmukh and Chaudhari, 2011), green concept (Govindan, Rajendran, Sarkis, and Murugesan, 2015; Igarashi, De Boer, and Fet, 2013), sustainable development (Zimmer et al., 2015), lean or agile manufacturing strategies (El Mokadem, 2017), and the integration of uncertainty in the decision-making process (Keshavarz Ghorabaee et al., 2017a), particularly with the adoption of the fuzzy set theory (Simić et al., 2017). Most recently, Ocampo et al. (2018) offered the most updated review on the approaches of supplier selection and pointed out that the emerging themes in the domain literature include uncertain environment, risks, and sustainability. Furthermore, MCDM, fuzzy decision-making, and mathematical programming are considered popular approaches (Ocampo et al., 2018).

Various factors, which may be conflicting, are taken into account in the supplier selection problem. These factors have contributed to the degree of complexity when determining the criteria set (decision framework) for the problem. These factors may be industry, country, or even company-specific and may give rise to the need for the determination of unique (and most appropriate) decision frameworks and approaches in different contexts. Wu and Barnes (2011) pointed out that all approaches used in partner (supplier) selection are equally useful in all situations although the current literature seems not to address this issue adequately. These factors are categorized differently in various works. Several previous studies have attempted to classify some of these factors into economic, environmental, and social factors (Chang et al., 2009; Feng et al., 2011; Junior et al., 2014; Liu & Zhang, 2011; Punniyamoorthy et al., 2011; Yücel & GüNeri, 2011). Alternatively, these factors are also classified as internal and external criteria involving benefits and costs elements.

While the supplier selection problem has been well-studied under the manufacturing domain due to the significant number of raw materials and parts that require suppliers along the supply chain (Tahriri et al., 2008), the oil and gas industry faces similar issues, but only a handful of papers have been reported in the current literature. To date, to the best of our knowledge, there are only seven published works that demonstrate theoretical discussions and case studies of supplier selection in the oil and gas industry. Luzon and El-Sayegh (2016) attempted to identify critical criteria in the supplier selection using the Delphi method and the analytic hierarchy process (AHP). An intuitionistic-fuzzy-TOPSIS-method-with-flexible-entropy-weighting was proposed by Wood (2016) in identifying the best supplier for petroleum industry facilities under a set of 30 criteria. On supplier selection and order allocation problems, Arabzad et al. (2015) proposed the use of the SWOT analysis and fuzzy TOPSIS in ranking suppliers and mixed-integer linear programming (MILP) is used to determine the optimum allocation to each supplier. The analytic hierarchy process (AHP) was also used by Boostani et al. (2018) to rank the candidate suppliers, and multi-objective linear programming is adopted for determining the best supplier and for solving the order allocation problem in a gas industry in Iran. Conceptual works were reported in the current literature. These works include Sepehri (2013) on developing a fundamental framework for supplier portfolio management, including supplier selection and empowerment, for oil and gas industries in Iran; Haque et al. (2004) on identifying the critical success and failure factors for the upstream oil and gas industry in the UK; and, Yusuf et al. (2012) on empirically studying the relationships of supply chain agility, competitiveness, and performance in the oil and gas industry and promoting the idea of innovation and risk-taking for prosperity in this industry. From this list, it can be observed that only three papers are directly addressing the supplier selection problem despite its criticality in the oil and gas industry.

The methodological approaches offered by these three papers (i.e., Wood, 2016; Arabzad et al., 2015; Boostani et al., 2018) addressing the supplier selection problem suffer some crucial shortcomings. For instance, Wood (2016) failed to point out how the 30 supplier selection criteria were generated. Although Wood (2016) mentioned that some "unique geographic and organizational factors" must be taken into every supplier selection problem, he failed to demonstrate how these factors would be implemented in real-life scenarios. Due to the unique factors and the local conditions of a particular oil and gas industry, it is thus imperative that supplier selection criteria must be participated and agreed by the stakeholders and key decision-makers of a particular case through a consensus-generating platform. With three decision-makers in the case of Wood (2016), it is not appropriate to adopt fuzzy set theory as explained by Ng and Deng (1995). Instead, the use of grey system theory is more appropriate. Wood (2016) did not also offer a rigorous approach in determining criteria weights or importance which is critical when local conditions of the supplier selection problem in the oil and gas industry are taken into consideration. The use of MILP in supplier selection and order allocation as demonstrated by Arabzad et al. (2015) and Boostani et al. (2018) does not guarantee a holistic approach since some essential qualitative supplier selection criteria may not be addressed in a formal mathematical programming technique. It is crucial as it may result to counterintuitive solutions to the supplier selection problem especially when local conditions strongly describe qualitative criteria (e.g., the degree of fit, collaboration, corporate social responsibility, among others). To promote inclusivity, both quantitative and qualitative criteria which may be challenging to measure must be addressed in the supplier selection problem. Finally, the use of the AHP offered by Boostani et al. (2018) may not be suitable when more than seven (or seven plus or minus two) criteria or alternatives exist in the problem as it distorts the consistency and redundancy in judgments in the pairwise comparison matrices (Saaty and Özdemir, 2003; Ocampo et al., 2018). Moreover, with n criteria and m suppliers, the total number of pairwise comparisons in the AHP is $(n(n-1) + nm(m-1))/2$, increasing either n or m or both generates a second-order increase in the number of judgments to be performed by key decision-makers (Ocampo et al., 2018). In light of these identified crucial shortcomings, this paper offers a methodological approach that attempts to overcome these gaps in the current literature of supplier selection in the oil and gas industry and it is considered as the main departure of this work.

Thus, the current study attempts to address both the application and methodological gaps and offers a hybrid-modified approach in supplier selection that is suitable in the oil and gas industry. As mentioned, the use of the AHP, as a widely-known approach in supplier selection (Ho et al., 2010; Agarwal et al., 2011; Govindan et al., 2015; Ocampo et al., 2018), is not suitable when a substantial number of criteria and alternatives (i.e., candidate suppliers) exists. On the other hand, handling uncertainty as an emerging theme in the current supplier selection literature (Ocampo et al., 2018) can be best addressed using grey system theory (rather than fuzzy set theory) when considering small sample uncertainty (e.g., few decision-makers) (Ng and Deng, 1995). This approach is a departure of the use of fuzzy set theory put forward by Wood (2016). In this work, utilizing the grey-Delphi approach, the relevant criteria were refined and identified through a series of interviews and discussions with managers from the Iranian oil and gas industry which addresses the lack of a consensus-generating platform for criteria selection in the work of Wood (2016). The joint grey-Shannon Entropy and grey-EDAS methodology are introduced to aid in the evaluation and selection of optimal suppliers for cooperation. The use of the grey-Shannon Entropy advances the lack of a rigorous approach of deriving criteria weights of Wood (2016) and the use of Boostani et al. (2018) of the AHP with the limitation on the number of criteria or suppliers. The grey-Shannon Entropy can adequately handle the uncertainty of the judgments in decision-making and a finite number of supplier selection criteria which may not be possible with the use of the AHP. The grey-EDAS methodology, on the other hand, advances the adoption of qualitative criteria in the supplier selection problem which is not possible with the use of mathematical programming techniques utilized by Arabzad et al. (2015) and Boostani et al. (2018). The grey-EDAS can also adequately handle the judgment uncertainty in selecting the best supplier from a finite number of candidate suppliers. The general objective of this study is to evaluate, rank and select optimal suppliers for an Iranian oil and gas company based on some unique and focused criteria set derived by considering country, industry, and company-specific conditions. The methodological route proposed in this paper is consistent with the framework of Wu and Barnes (2011) which suggests that situational characteristics and local conditions of the supplier selection problem must be emphasized to determine the most suitable methodology.

The following specific research objectives are addressed in this paper: (1) to identify and introduce a unique criteria framework through a combination of literature review and grey-Delphi approach for guiding supplier selection decisions in the oil and gas sector, (2) to introduce and integrate Shannon-Entropy and EDAS methodologies under grey environment for aiding the supplier selection decision-making, (3) to investigate, through a case study, a supplier evaluation and selection problem in an oil and gas sector context, and (4) to elaborate managerial and practical implications of the study.

In light of the gaps in the current literature as explicitly identified in the preceding discussions, the contributions of this research are manifold. First, to address the drawback of Wood (2016) in criteria selection, a unique decision framework for guiding the supplier selection decision making in the oil and gas sector is introduced, serving as the first contribution of this paper. Second, the paper develops a multi-criteria decision-aiding tool that integrates grey system elements with Shannon-Entropy and EDAS method that is capable of determining criteria importance weights and selecting optimal suppliers among others under grey environment, contributing to the decision-making literature and advancing the limitations of Arabzad et al. (2015), Wood (2016), and Boostani et al. (2018) in the lack of rigorous method in criteria importance weighting and inclusivity of qualitative criteria which are both crucial in the supplier selection problem in the oil and gas industry. Third, investigation of supplier selection in an Iranian oil and gas company context using empirical data contributes to the supplier selection literature, advancing our understanding of the subject matter from an emerging economy perspective.

This rest of the paper is structured as follows. Theoretical background comprising of supplier selection initiatives and research gap is presented in Section 2. Next, Section 3 presents the research methodology composed of the methods and tools utilized in carrying out the supplier selection problem. In Section 4, a real-world case application of the decision framework and the discussion of the results as well as managerial and practical implications are provided, and a sensitivity analysis of the results is presented in Section 5. In Section 6, the conclusions and managerial implications are elaborated, with a discussion of limitations and opportunities for future work.

2. Theoretical development

Supplier selection is one of the popular and much-discussed topics in the SCM literature. Many firms face the difficulty in selecting suppliers with the highest reputation in their industry to help them meet their customers' needs. Identifying suppliers who meet all criteria that a buying organization needs is almost impossible. Thus, firms identify suppliers that meet the ideal standard in starting cooperation. Many studies have proposed the use of different decision frameworks and decision support frameworks to aid in determining the optimal/ideal suppliers. Vinodh et al., (2011) proposed a fuzzy analytic network process (FANP) method for supplier selection in manufacturing organizations. They developed a supplier selection hierarchy structure with five criteria including risks, services, quality, the extent of fitness, and business improvement, and some sub-criteria in the electronic manufacturing companies. In another study conducted by Shemshadi et al. (2011), they applied fuzzy VIKOR with entropy measure for supplier selection using a five-criterion set including products quality, effort to establish cooperation, supplier's technical level, supplier's delay on delivery and price. In this study, Shannon entropy was used in determining the criteria weights while fuzzy VIKOR was utilized in determining the optimal suppliers.

Shaw et al., (2012) integrated and used FAHP and multi-objective linear programming for sustainable supplier selection guided by a five-criterion framework including cost, quality, lead time, greenhouse gas emission and demand. Sanayei, Mousavi, & Yazdankhah, (2010) in their study, proposed and used fuzzy VIKOR model for supplier selection. Their study considered production quality, price, supplier technology and flexibility as the criteria set for assessing the suppliers. The trapezoidal linguistics numbers were applied for obtaining preferences of experts. In another context, Liao & Kao (2011) investigated the supplier selection problem using an integrated TOPSIS and multi-choice goal programming (MCGP) approach. Their study utilized five criteria set including relationship closeness, quality of production, delivery capability, warranty level, and experience time. Moreover, Liao & Kao (2010) in their other study proposed a supplier selection aiding model based on the integration of the Taguchi Loss Function, AHP, and

MCGP approach. Their study utilized production quality, price, delivery time, service satisfaction, and warranty degree as criteria for guiding the supplier evaluation decision.

Kuo et al. (2010) integrated artificial network, Data Envelopment Analysis, and ANP into a unified model and applied this model for supplier selection. The study developed a hierarchy structure with five top criteria including service, corporate social responsibility, cost, delivery, environment and quality and a number of sub-criteria consisting of fulfill rate, lead time, order frequency, performance value, sectorial price behavior, transportation cost, Eco-Design Requirements for Energy Using Products (EUP), Ozone depleting chemicals (ODC), Restriction of Hazardous Substances (RoHS), a certificate for environment management ISO14001, Waste Electrical and Electronic Equipment (WEEE), process improvement, management commitment to quality, reject rate, warranties and quality assurance. In this study, Delphi method was used to aid in the refinement of the criteria initially identified from the literature review and weighs of these criteria obtained by ANP method, with the performance value of the suppliers measured by Artificial Neural Network (ANN). In the final step, the weights of criteria and performance values of the suppliers were combined in the DEA method to determine the optimal supplier. In another study conducted by Kilincci & Onal (2011) proposed and utilized a fuzzy AHP model for washing machine supplier selection. The study developed a hierarchy structure of three top and main criteria including supplier, product performance and service performance with a number of sub-criteria under these main criteria comprising of financial status, management, technical ability, quality system, geography location, capacity, working with Kanban approach, price, handling, production quality, follow-up, lead time, technical support and professionalism. The triangular fuzzy numbers were applied to help determine the decision-makers' preferences in the pairwise comparison of AHP.

Chang, Chang & Wu, (2011) used fuzzy DEMATEL approach for developing supplier selection criteria. The study considered production quality, stable delivery, demand change in time, service, price, delivery performance, technical ability, production capability, financial situation, and lead-time as decision criteria. They combined triangular fuzzy numbers and DEMATEL method to evaluate supplier performance and select optimal suppliers. In another study, Deng & Chan (2011) proposed and used a novel MCDM approach that integrates basic probability assignments (BPA), Dempster-Shafer Theory in a fuzzy environment (FDST) for investigating supplier selection problem. In their study, they introduced and used criteria including product delivery, cost, risk factor and supplier's service performance in guiding this investigation. Within this investigation, they determined BPA and after that, used the FDST to integrate all criteria data into a single score of the alternatives in the systems and select the optimal option. Gupta & Barua (2017), in their study, integrated and applied the best-worst method (BWM) and fuzzy TOPSIS for supplier selection among small-medium enterprise (SMEs) considering green innovation criteria. They considered criteria including collaboration, environment investment, resource availability, environment management, research and design initiatives, green purchase, regulatory and 42 sub-criteria for guiding the evaluation of these companies. Table 1 depicts the many and diverse factors for guiding supplier selection**.**

Table 1. Supplier selection criteria from the literature

Author(s)	Criteria
Chamodrakas et al. (2010)	Cost, quality, delivery
Chen (2011)	Lead time, discount, on-time delivery, flexibility delivery, service, responsiveness, process, corporation, inventory
Chang et al. (2011)	Product quality, Stable delivery of goods, Reaction to demand change in time, Service, Product price, Delivery performance, Technology ability, Production capability, Financial situation, Lead-time
Büyüközkan & Çifçi (2011)	Time, cost, quality, flexibility, organization, service quality, technology, social responsibility
Bai & Sarkis (2010)	Environmental practices, Pollution controls, Remediation, End-of-pipe controls, Pollution prevention Product adaptation, Process adaptation, Environmental management system, Establishment of environmental commitment and policy, Identification of environmental aspects, planning of environmental objectives, Assignment of environmental responsibility, Checking and evaluation of environmental activities, Environmental performance Resource consumption, Consumption of energy, Consumption of raw material, Consumption of water, Pollution production, Production of polluting agents, Production of toxic products Production of waste
Zeydan et al. (2011)	New Project Management, Supplier Management, Quality and Environmental Management, Production Process Management, Test and Inspection Management, Corrective Preventive Actions Management
Kilincci & Onal,(2011)	Financial issue, management, technical ability, quality, geographic location, capacity, price, quality, follow-up, lead time,
Kannan et al., (2013)	Cost, quality, delivery, technology capability, environmental competency
Sanayei et al., (2010)	product quality, On-time delivery, Price/cost, Supplier's technological level, Flexibility
Liao & Kao (2010)	Relationship closeness, quality, delivery, warrant level, experience time

Note that the preceding review is not intended to be exhaustive. Much attention has been given to the supplier selection problem such that a significant number of review papers has been reported in the current literature. These include the literature reviews of De Boer et al. (2001) and Bhutta (2003) emphasizing on the methodological frameworks of the supplier selection problem, Tahriri et al. (2008) on manufacturing industries, Deshmukh and Chaudhari (2011) on criteria and methods of the problem, Ware et al. (2012) with published works in 1991-2011, and Chai et al. (2013) on decision-making techniques. These reviews focus on the structure along with the criteria and the methodological approaches of the supplier selection problem. They highlight the role of MCDM techniques in supplier selection due to the quantitative and qualitative criteria addressed in most published works, especially the AHP (Tahriri et al., 2008). These were given more emphasis by Ho et al. (2010), Agarwal et al. (2011), and Govindan et al. (2015) when they review papers focusing the adoption of MCDM techniques.

Furthermore, the current trend on pressing environmental initiatives and regulations has shaped the supplier selection problem towards "green" supplier selection, "sustainable" supplier selection and "Lean or agile" supplier selection as demonstrated by the review papers of Igarashi et al. (2013), Govindan et al. (2015), Zimmer et al. (2015) and El Mokadem (2017). Another milestone in the literature, and is considered as the most recent, is the integration of uncertainty in the supplier selection problem which is addressed by the review works of Keshavarz Ghorabaee et al. (2017a) and Simić et al. (2017). Collectively mapping the last decade themes of the domain literature, the recent review of Ocampo et al. (2018) found that the emerging themes in the domain literature include uncertain environment, risks, and sustainability and the most popular approaches include MCDM, fuzzy decision-making, and mathematical programming. Ocampo et al. (2018) also pointed out that most prevalently used techniques are the integrated fuzzy approaches and the most commonly applied theme is the uncertain environment. It implies that recent studies on supplier selection have placed much emphasis on overcoming the subjective and human factors inherent in supplier selection decisions (Ocampo et al., 2018). These findings are consistent with the review findings of Wu and Barnes (2011) which pointed out that most popular combined approaches of supplier selection are the models that include mathematical programming, AHP/ANP or fuzzy set approach.

In the context of the oil and gas industry, the supplier selection problem has not received much attention as evidenced by a handful of works in the current literature. Luzon and El-Sayegh

(2016), while addressing the oil and gas projects in the UAE, identified a set of appropriate supplier selection criteria from 23 criteria proposed by Dickson (1966) by first conducting a survey on the importance of each criterion and choosing the top ten criteria from this set. They grouped them into technical and commercial aspects (which include quality, price, delivery, service, and warranties and claims) and company-related aspects (which include technical capability, production facility and capability, financial position, performance history, and geographical location). Then, AHP and Delphi were then used to provide weights of the top ten criteria. The pointed out that technical and commercial criteria are more important than the company-specific criteria. Despite this, the selection hierarchy used in the AHP is too simplistic and may not appropriately convey the decision-making problem. Using a set of 30 qualitative and quantitative criteria, Wood (2016) proposed the use of the intuitionistic-fuzzy-TOPSIS-method-with-flexible-entropy-weighting method by arguing that these approaches have little attention in supplier selection in the petroleum industry. Boostani et al. (2018), on the other hand, capitalized on the supplier selection and order allocation problem where they proposed six evaluation criteria which include quality, environmental concerns, cost, services, suppliers' backgrounds, and risk factors. Each criterion has some sub-criteria to elicit the supplier selection problem appropriately. Boostani et al. (2018) used the AHP in ranking five suppliers and multi-objective linear programming for determining the best supplier and their allocated orders. With gas industry in Iran as the case study, Arabzad et al. (2015) addressed the supplier selection and order allocation problem by considering price, quality, delivery, and after-sales services as internal criteria while reputation and position in industry, design capability, financial stability and credit strength, equipment and capacity, and geographical location as external criteria. The SWOT analysis was used in grouping these criteria. Fuzzy TOPSIS was then used to rank the candidate suppliers, and MILP was used to allocate quantity to each supplier.

The preceding review presented depicts that even though various frameworks of supplier selection decision criteria have attempted to address the problem with supplier selection, little attention has been received by the oil and gas industry. Out of the four supplier selection studies in the oil and gas industry, only three works have demonstrated the entire supplier selection problem since the work of Luzon and El-Sayegh (2016) only focus on the selection of the criteria. The works of Boostani et al. (2018) and Arabzad et al. (2015) have limited evaluation criteria with no rigorous formulation and qualification processes which may affect the final selection process.

Wu and Barnes (2011) pointed out that the quality of the final selection process depends on the previous process (i.e., criteria formulation, qualification, and application feedback). Furthermore, the AHP as used by Boostani et al. (2018) may not be appropriate when more criteria or suppliers are considered (Ocampo et al., 2018). The fuzzy set theory as proposed by Wood (2016) and Arabzad et al. (2015) may not also be appropriate in handling uncertainty when a small sample is considered (Ng and Deng, 1995). The oil and gas industry is a vital industry to the Iranian government as the primary driver of the economy. Thus, identifying the best/optimal suppliers that can partner with companies in the oil and gas industry to supply materials or services to them is crucial to the industry. Being the main drivers, the performances of companies in the oil and gas industry seriously affect the performance of the Iranian economy. As a result, identifying and selecting essential and relevant criteria to help select suitable suppliers is highly necessary. This paper, therefore, uses grey-Delphi approach to help integrate the many and diverse criteria set, evaluate and refine these criteria to select the more relevant and most important criteria for the oil and gas industry (see Tables 2 and 3 for details). In addition to the framework determination, this study proposed a hybrid multi-criteria decision-making aiding tool that integrates Delphi, Shannon Entropy and EDAS techniques under grey environment that introduces accurate computation to help in the supplier selection process overcoming the weakness in AHP, TOPSIS and VIKOR techniques (Keshavarz Ghorabaee, Zavadskas, Olfat, & Turskis, 2015) which have dominated the supplier selection literature.

3. Research methodology

This study adopts the case study approach to investigate the supplier selection problem in the oil and gas industry. The study utilizes 12 managers with not less than 25years working experience from an Iranian oil and gas company to exemplify the applicability and robustness of the proposed decision framework for guiding the supplier selection decision problems. The company and respondent managers were selected based on a convenient sampling approach. The decision aiding tool utilized is composed of grey systems theory, Shannon-Entropy, and EDAS, with details of each of these tools provided separately in section 3.1 and the proposed novel integrated tool also detailed in section 3.2.

3.1. Methods

3.1.1 Grey systems theory

In the real-world problems, the decision makers often face uncertainty due to insufficient and incomplete information. Grey systems theory (Deng, 1982) is one of the effective logic that enables decision-makers to model the inherent uncertainty in decision-making problems (Bai, Sarpong & Sarkis, 2017; Li & Chen, 2019). Most often, qualitative data collected are subjective, and that grey set theory is utilized to deal with the imprecision and vagueness involved with the judgment. This study adopts the grey systems theory to deal with such kind of problem inherent and anticipated with the qualitative data. Within the grey theoretic concept, there are three categories for the information: (1) white with certain information, (2) grey with insufficient information, (3) black with completely unknown information (for more information, please refer to Liu & Forrest, 2010; Liu et al. 2012). Interval grey numbers are the central concept within the grey system theory. We now introduce some basic definitions about interval grey numbers and their operations as follows:

Definition 1: Let $\otimes x$ be a grey number and $\otimes x = [\underline{x}, \overline{x}] = [x' \in x \mid \underline{x} \le x' \le \overline{x}]$ be an interval grey number where $\underline{x}$ and $\overline{x}$ are known lower and upper limits of $\otimes x$, respectively with unknown distribution information of x (Deng, 1989; Bai et al., 2017).

Definition 2: Let two interval grey numbers be $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$. Some mathematical operations of the interval grey numbers are given as follows (equations 1 to 4):

$$\otimes x_1 + \otimes x_2 = [\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2] \tag{1}$$

$$\otimes x_1 - \otimes x_2 = [\underline{x}_1 - \overline{x}_2, \overline{x}_1 - \underline{x}_2] \tag{2}$$

$$\otimes x_1 \times \otimes x_2 = [\min(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2),\ \max(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2)] \tag{3}$$

$$\otimes x_1 \div \otimes x_2 = [\underline{x}_1, \overline{x}_1] \times [\frac{1}{\underline{x}_2}, \frac{1}{\overline{x}_2}], 0 \notin \otimes x_2 \tag{4}$$

Definition 3. For a general interval grey number $\otimes x = [\underline{x}, \overline{x}] = [x' \in x \mid \underline{x} \le x' \le \overline{x}]$, consider $\tilde{\otimes}$ as its whitenization value. Equation (5) is used when the distribution of $\tilde{\otimes}$ is unknown as below (Liu & Forrest, 2010; Liu et al. 2012):

$$\tilde{\otimes} = \alpha \times a_{\otimes} + (1-\alpha)b_{\otimes},\ \alpha \in [0,1] \tag{5}$$

If the α coefficient is 0.5, $\tilde{\otimes}$ is known as equal-weight mean whitenization which is a commonly used value for α (Liu & Forrest, 2010). It should be noted that this study conducted whitenization operations on all grey numbers to transform them into crisp numbers.

3.1.2 Shannon Entropy

MCDM methods can be categorized into two. The first category is about finding priority based on the pairwise comparison and the second is based on a decision matrix. Shannon entropy which is introduced by Shannon (Shannon, 1948) is one of the MCDM methods that works based on a decision matrix. After its introduction, this model has been applied in various fields (Bian, & Yang, 2010; Lin, 1991; Schug et al., 2005; Bruhn, Lehmann, Röpcke, Bouillon, & Hoeft, 2001). The processes for computing this method is depicted below:

Step 1. Determining decision-makers (DMs) preferences and setting the decision-making matrix;

Step 2. Determining the negative or positive alternatives;

Step 3. Normalising the data of decision matrix;

Step 4. Determining the entropy E_j of each alternative applying Equation (6):

$$E_j = -k\sum_{i=1}^{m}[P_i . \ln P_i] \quad \text{j=1, 2,…, n} \qquad \text{and k=}\frac{-1}{\ln m} \tag{6}$$

Step 5. Calculating the differential of each alternative (d_j);

Step 6. Determining the final weights W_j by using Equation (7):

$$W_j = \frac{d_j}{\sum_{i=1}^{n} d_j} \tag{7}$$

3.1.3 EDAS method

Evaluation based on Distance from Average Solution (EDAS) is one of the MCDM methods that can be categorized as a decision matrix approach. Other methods with a similar concept to EDAS include TOPSIS, VIKOR, ARAS, COPRAS, and MOORA. In these methods, the best alternative is determined by calculating the distance from positive-ideal and negative-ideal solutions. The positive-ideal solution is the nearest distance to the best solution, and the negative-ideal solution is the furthest distance to the best solution, and this mechanism would be vice versa in the worst solution. The significant difference between these methods and EDAS method is that, in EDAS, the best solution is the nearest distance to the average solution. It means that in the EDAS method there is no need to calculate for the positive-ideal and negative-ideal solutions. In the EDAS method, we have two parameters to calculation including Positive Distance from Average (PDA) and Negative Distance from Average (NDA). The best alternative has the highest value of PDA and lowest value of NDA. The steps of the EDAS method are explained as follows:

Step 1. In this step, criteria and alternatives are defined.

Step 2. Formulating a decision-making matrix based on decision-makers preferences of alternatives and criteria are performed (see Equation 8):

$$A=[X_{ij}]_{n\times m}=\begin{bmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{bmatrix} \tag{8}$$

where

X_{ij} represents the preference of alternative i with respect to criterion j, n is the number of alternatives and m is he number of criteria

Step 3. Average Solution (AS) is calculated using Equation (9):

$$AS=[AS_j]_{1\times m} \tag{9}$$

where

$$AS_j=\frac{\sum_{j=1}^{n} x_{ij}}{n}$$

Step 4. In this step, positive distance and negative distance from average based on the type of criteria (benefit and cost) are calculated (See Equations (10) to (15)):

$$PDA=[PDA_{ij}]_{n\times m} \tag{10}$$

$$NDA=[NDA_{ij}]_{n\times m} \tag{11}$$

If the type of criterion is a benefit, then Equations (8) and (9) are applied:

$$PDA_{ij}=\frac{\max(0,(x_{ij}-AS_j))}{AS_j} \tag{12}$$

$$NDA_{ij}=\frac{\max(0,(AS_j-x_{ij}))}{AS_j} \tag{13}$$

If the type of criterion is a cost, then Equation (10) and (11) are applied:

$$PDA_{ij} = \frac{\max(0,(AS_j - x_{ij}))}{AS_j} \tag{14}$$

$$NDA_{ij} = \frac{\max(0,(x_{ij} - AS_j))}{AS_j} \tag{15}$$

Step 5. Compute weighted sums of PDA (SP) and NDA (SN) for all alternatives by Equations (16) and (17) as below:

$$SP_i = \sum_{j=1}^{m} w_j PDA_{ij} \tag{16}$$

$$SN_i = \sum_{j=1}^{n} w_j NDA_{ij} \tag{17}$$

In these formulas w_j indicates the weights of criteria.

Step 6. SP and SN values must be normalized for all alternatives using Equations (18) and (19) as follow:

$$NSP_i = \frac{SP_i}{max_i(SP_i)} \tag{18}$$

$$NSN_i = 1 - \frac{SN_i}{max_i(SN_i)} \tag{19}$$

Step 7. Finding the appraisal score (ASC) for all alternatives (based on Equation 20):

$$ASC_i = \frac{1}{2}(NSP_i + NSN_i) \tag{20}$$

That $0 \leq ASC_i \leq 1$

Step 8. Ranking alternatives based on ASC. The alternative with the highest score receives the highest priority (Keshavarz Ghorabaee et al., 2015).

3.2 Proposed Methodology

3.2.1 Integrated Grey-Delphi-Shannon Entropy-EDAS method

In this study, we propose a three-phase decision-making framework as depicted in Figure 1.

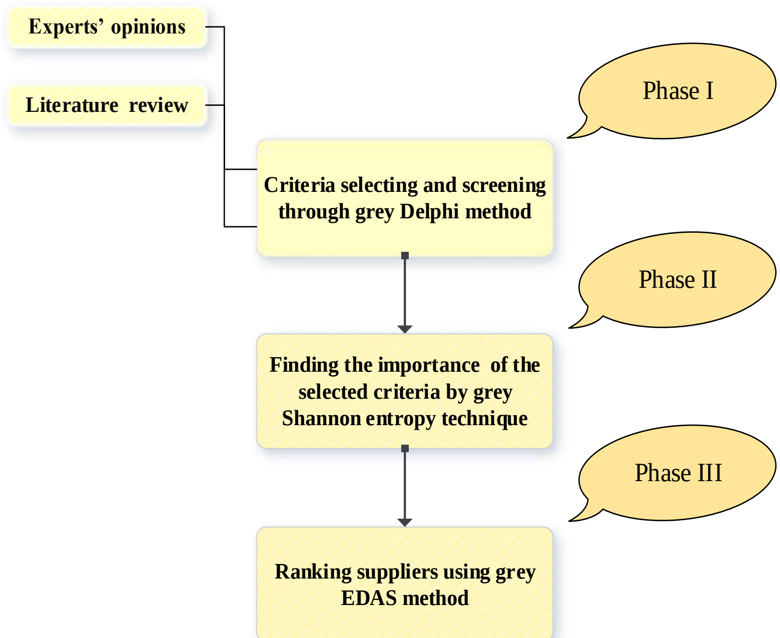

Figure 1. Research framework of the study

Phase I: In this phase, potential criteria are initially identified from previous works through a literature review. Then, relevant and important criteria are determined through grey Delphi method. A questionnaire based on these criteria and five-point grey-interval numbers scale is designed and distributed to the panel members. Then, the preferences of each member are gathered and analyzed. After the analysis, if the average of any criterion is less than an agreed threshold, then this criterion is eliminated, otherwise, considered as relevant and important criteria to be part of the decision framework for this research.

Phase II: In this phase, decision-makers initially rate all the criteria using the 5-point grey-interval numbers scale. Using the equations presented in section 3.1, all criteria relative importance weights are determined. The result of this section provides criteria for importance weights.

Phase III: Since EDAS method requires criteria importance weights to enable to calculate and rank alternatives, the approach adopts the grey Shannon entropy criteria importance weights. This integrated approach is used for aiding the selection of a suitable/optimal supplier.

3.2.2 Justification for utilizing integrated Grey-Delphi-Shannon Entropy-EDAS method

Considering the inherent uncertainty in decision-making problems, such as one currently been studied, there are three mostly applied techniques for dealing with systems' uncertainty: probability and statistics, fuzzy set theory, and grey systems theory. Among these, the grey system theory is more applicable when decision-makers are dealing with a small sample of the studied problem (Liu & Forrest, 2010). Since this study considered a small sample size (12 industrial managers), it was more appropriate and justifiable to use the grey systems theory.

The first objective of this study was to identify some potential evaluating criteria and refined them to suit the Iranian oil and Gas industry context using opinions from industrial managers of the industry. We, therefore, utilized Delphi method since its main advantage is the ability to guide group judgments towards a final decision (McKenna, 1994) and has been utilized in many sciences and engineering problems (Kauko & Palmroos, 2014; Modrak & Bosun, 2014; Tang, Sun, Yao & Wang, 2014). Another objective of the study was the determination of the relative importance of these evaluation criteria. There are many methods such as AHP, ANP, BWM, (Kusi-Sarpong, Sarkis & Wang, 2016a, b; Badri Ahmadi, Kusi-Sarpong & Rezaei, 2017) available to achieve this goal. However, Shannon entropy was chosen over the other tools because the number of criteria (16 in this case) and we were unable to use any pairwise comparison-based method engrained with difficulties in computing inconsistencies.

The EDAS method was selected over the other similar methods such as VIKOR and TOPSIS for aiding the supplier evaluation and selection problem based on its simplicity (Keshavarz Ghorabaee et al. 2015). Example, EDAS uses the simple arithmetic mean to efficiently compute the desirability of alternatives based on the negative and positive distances from the average solution (Keshavarz Ghorabaee et al., 2017b). Hence, we integrated these tools (Delphi, Shannon entropy and EDAS methods under grey environment) into a unique and unified method for aiding criteria refinement and evaluation, ranking and selection of optimal suppliers in a more reliable manner.

4. Real World Application

4.1 Case company

Our case study is the National Iranian Oil Company (NIOC). This company was established in 1951 for directing and making policies for exploration, drilling, production, research and development, refining, distribution and export of oil, gas, petroleum products. NIOC is one of the world's largest oil and gas companies because of its vast amount of oil and gas resources. It is estimated that the company holds 156.53 billion barrels of liquid hydrocarbons and 33.79 trillion cubic meters of natural gas. Considering the advances in technology and increasing complexities of economic and political relations with other countries, NIOC has risen to a privileged status. Therefore, national and regional policies and cooperation with industrial countries in the provision of energy supply and stabilizing global oil markets are on the agenda of NIOC. NIOC has different sectors while supervising oil industry activities. The company has taken significant steps toward establishing business enterprises, funded financial resources for development, helped to update technologies for exploration, drilling, and production with reliance on the knowledge of Iranian experts. NIOC consists of seventeen production companies, eight technical service companies, seven management, six divisions (administrative units) and five organizational units.

Iranian's economy depends on revenue of oil and gas sold. The share of selling oil and gas in the budget of Iran is significant. It means that the government makes an account of this revenue. Therefore, oil and gas have a prominent role in Iran. Extraction, refining, and selling of oil are done solely by NOIC as the governmental organization. After three decades of war between Iran and Iraq, the government decided to allow private companies into the sector. Hence, many works that were done by government-controlled companies were switched to private companies. Therefore, the issue of monopole disappeared, and many companies were allowed to partake in doing business with NIOC. After that, the supplier selection issue emerged for NIOC and required the selection of best companies based on many factors that affected their operations. The activities of these private companies are vital since any inaccuracies or delays may affect the operations of extraction, refinement, and selling. This research helps NIOC to select the best supplier to support their operations.

4.2 Application of the proposed approach

Phase 1: Criteria selection and screening through Grey Delphi method

In the first phase, a questionnaire based on the criteria was designed and sent by fax and email to each Delphi panel member. The Delphi panel comprised of 12 decision-makers of the oil and gas industry including CEO and senior managers with over 25 years working experiences in this industry and had a master or higher academic degree in the related field. Then all the Delphi members were requested to make their judgments on the selected evaluation criteria. We did explain to them that they could choose any of the grey numbers related to each 5-point linguistic scale including strongly unimportant, unimportant, moderately important, important and strongly important scales. The scales are as shown in Table 2.

Table 2. Linguistic scale and associated grey numbers for importance rating

5-Point Linguistic Scale	Strongly Unimportant (SUI)	Unimportant (UI)	Moderately important (MI)	Important (I)	Strongly important (SI)
Grey interval Number	[0,1]	[1,2]	[2,3]	[3,4]	[4,5]

Based on the industrial managers' experiences, all their preferences were collected as interval grey numbers and are indicated in Table 3. After that, the grey data were whitened using Equation (5), and the results are shown in Table 4.

Table 3. Grey Data as inputs to the Delphi method

	expert 1	expert 2	expert 3	expert 4	expert 5	expert 6	expert 7	expert 8	expert 9	expert 10	expert 11	expert 12
Risks	[3,4]	[4,5]	[3,4]	[4,5]	[1,2]	[2,3]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]	[2,3]
services	[4,5]	[3,4]	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[2,3]	[4,5]	[3,4]	[4,5]	[3,4]
quality	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]
extent of fitness	[3,4]	[2,3]	[1,2]	[4,5]	[3,4]	[4,5]	[3,4]	[2,3]	[3,4]	[2,3]	[1,2]	[2,3]
business improvement	[2,3]	[4,5]	[2,3]	[4,5]	[2,3]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]	[3,4]	[2,3]
lead time	[4,5]	[3,4]	[4,5]	[3,4]	[3,4]	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[2,3]
greenhouse gas emission and demand	[1,2]	[2,3]	[1,2]	[4,5]	[3,4]	[1,2]	[2,3]	[2,3]	[4,5]	[2,3]	[1,2]	[2,3]
effort to establish cooperation	[4,5]	[3,4]	[3,4]	[3,4]	[2,3]	[4,5]	[2,3]	[3,4]	[3,4]	[2,3]	[4,5]	[3,4]
supplier's technical level	[4,5]	[4,5]	[4,5]	[3,4]	[3,4]	[2,3]	[3,4]	[1,2]	[2,3]	[4,5]	[3,4]	[4,5]
supplier's delay on delivery and price	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]	[2,3]	[4,5]	[4,5]
relationship closeness	[4,5]	[4,5]	[3,4]	[3,4]	[3,4]	[4,5]	[3,4]	[4,5]	[4,5]	[2,3]	[1,2]	[2,3]

delivery capability	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]	[2,3]	[4,5]	[3,4]	[4,5]	[2,3]	[4,5]
warranty level and experience time	[3,4]	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]	[2,3]	[1,2]	[2,3]	[4,5]	[3,4]	[4,5]
corporate social responsibility	[2,3]	[3,4]	[2,3]	[3,4]	[2,3]	[4,5]	[1,2]	[2,3]	[4,5]	[3,4]	[2,3]	[4,5]
cost	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[2,3]	[3,4]	[4,5]	[2,3]	[4,5]	[3,4]	[4,5]
management	[4,5]	[3,4]	[2,3]	[3,4]	[3,4]	[2,3]	[3,4]	[4,5]	[3,4]	[4,5]	[4,5]	[3,4]
geography location	[2,3]	[1,2]	[2,3]	[3,4]	[2,3]	[3,4]	[4,5]	[2,3]	[3,4]	[4,5]	[3,4]	[2,3]
follow-up	[4,5]	[3,4]	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[2,3]	[3,4]	[4,5]	[2,3]	[4,5]
defects	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]	[2,3]	[3,4]	[4,5]	[2,3]	[3,4]
TQM	[2,3]	[2,3]	[2,3]	[3,4]	[2,3]	[3,4]	[4,5]	[2,3]	[3,4]	[4,5]	[2,3]	[4,5]
staff training	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[2,3]	[3,4]	[4,5]	[3,4]	[4,5]	[4,5]

Table 4. Whitenization values of grey Delphi Data

	expert 1	**expert 2**	**expert 3**	**expert 4**	**expert 5**	**expert 6**	**expert 7**	**expert 8**	**expert 9**	**expert 10**	**expert 11**	**expert 12**
Risks	3.5	4.5	3.5	4.5	1.5	2.5	4.5	3.5	4.5	3.5	4.5	2.5
services	4.5	3.5	4.5	4.5	3.5	4.5	3.5	2.5	4.5	3.5	4.5	3.5
quality	4.5	4.5	4.5	4.5	3.5	4.5	3.5	4.5	3.5	4.5	3.5	4.5
extent of fitness	3.5	2.5	1.5	4.5	3.5	4.5	3.5	2.5	3.5	2.5	1.5	2.5
business improvement	2.5	4.5	2.5	4.5	2.5	4.5	3.5	4.5	3.5	4.5	3.5	2.5
lead time	4.5	3.5	4.5	3.5	3.5	4.5	4.5	4.5	4.5	3.5	4.5	2.5
greenhouse gas emission and demand	1.5	2.5	1.5	4.5	3.5	1.5	2.5	2.5	4.5	2.5	1.5	2.5
effort to establish cooperation	4.5	3.5	3.5	3.5	2.5	4.5	2.5	3.5	3.5	2.5	4.5	3.5
supplier's technical level	4.5	4.5	4.5	3.5	3.5	2.5	3.5	1.5	2.5	4.5	3.5	4.5
supplier's delay on delivery and price	4.5	4.5	4.5	4.5	4.5	3.5	4.5	3.5	4.5	2.5	4.5	4.5
relationship closeness	4.5	4.5	3.5	3.5	3.5	4.5	3.5	4.5	4.5	2.5	1.5	2.5
delivery capability	4.5	4.5	3.5	4.5	3.5	4.5	2.5	4.5	3.5	4.5	2.5	4.5
warranty level and experience time	3.5	4.5	4.5	4.5	4.5	3.5	2.5	1.5	2.5	4.5	3.5	4.5

corporate social responsibility	2.5	3.5	2.5	3.5	2.5	4.5	1.5	2.5	4.5	3.5	2.5	4.5
cost	4.5	4.5	4.5	3.5	4.5	2.5	3.5	4.5	2.5	4.5	3.5	4.5
management	4.5	3.5	2.5	3.5	3.5	2.5	3.5	4.5	3.5	4.5	4.5	3.5
geography location	2.5	1.5	2.5	3.5	2.5	3.5	4.5	2.5	3.5	4.5	3.5	2.5
follow-up	4.5	3.5	4.5	4.5	4.5	3.5	4.5	2.5	3.5	4.5	2.5	4.5
defects	4.5	4.5	4.5	3.5	4.5	3.5	4.5	2.5	3.5	4.5	2.5	3.5
TQM	2.5	2.5	2.5	3.5	2.5	3.5	4.5	2.5	3.5	4.5	2.5	4.5
staff training	4.5	4.5	4.5	3.5	4.5	3.5	2.5	3.5	4.5	3.5	4.5	4.5

After gathering all the data in this phase, we analyzed them, and each criterion with the average score of lower than 3.5 was eliminated from the evaluation criteria. After the analysis, the result showed that 16 criteria out of the 21 criteria for supplier selection did meet and exceed the threshold and so were selected. The final results are as summarized in Table 5.

Table 5. Results of the Delphi method using grey data

Factor	Factor Initials	Average Score	Accept/Reject
Risks	C1	3.58	Accept
services	C2	3.91	Accept
Quality	C3	4.16	Accept
~~extent of fitness~~		~~3~~	~~Reject~~
business improvement	C4	3.58	Accept
lead time	C5	4	Accept
~~greenhouse gas emission and demand~~		~~2.58~~	~~Reject~~
effort to establish cooperation	C6	3.5	Accept
supplier’s technical level	C7	3.58	Accept
supplier’s delay in delivery and price	C8	4.16	Accept
relationship closeness	C9	3.58	Accept
delivery capability	C10	3.91	Accept
warranty level and experience time	C11	3.66	Accept
~~corporate social responsibility~~		~~3.16~~	~~Reject~~
Cost	C12	3.91	Accept
management	C13	3.66	Accept
~~geography location~~		~~3.08~~	~~Reject~~
follow-up	C14	3.91	Accept
defects	C15	3.83	Accept
~~TQM~~		~~3.25~~	~~Reject~~
staff training	C16	4	Accept

.

Phase II: Finding the importance of selected criteria by grey Shannon entropy technique

In this phase, we utilized grey Shannon entropy to calculate the criteria relative important weights. In the first step, a decision matrix based on grey data was populated and further whitened. Tables 6 and 7 depict the grey-based decision matrix and the whitened values as below:

Table 6. Grey data as the inputs of the Shannon entropy method

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
DM1	[3,4]	[4,5]	[4,5]	[2,3]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]
DM2	[4,5]	[3,4]	[4,5]	[4,5]	[3,4]	[3,4]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]	[3,4]	[4,5]	[4,5]
DM3	[3,4]	[4,5]	[4,5]	[2,3]	[4,5]	[3,4]	[4,5]	[4,5]	[3,4]	[3,4]	[4,5]	[4,5]	[2,3]	[4,5]	[4,5]	[4,5]
DM4	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]	[3,4]	[3,4]	[4,5]	[3,4]	[4,5]	[4,5]	[3,4]	[3,4]	[4,5]	[3,4]	[3,4]
DM5	[1,2]	[3,4]	[3,4]	[2,3]	[3,4]	[2,3]	[3,4]	[4,5]	[3,4]	[3,4]	[4,5]	[4,5]	[3,4]	[4,5]	[4,5]	[4,5]
DM6	[2,3]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[2,3]	[3,4]	[4,5]	[4,5]	[3,4]	[2,3]	[2,3]	[3,4]	[3,4]	[3,4]
DM7	[4,5]	[3,4]	[3,4]	[3,4]	[4,5]	[2,3]	[3,4]	[4,5]	[3,4]	[2,3]	[2,3]	[3,4]	[3,4]	[4,5]	[4,5]	[2,3]
DM8	[3,4]	[2,3]	[4,5]	[4,5]	[4,5]	[3,4]	[1,2]	[3,4]	[4,5]	[4,5]	[1,2]	[4,5]	[4,5]	[2,3]	[2,3]	[3,4]
DM9	[4,5]	[4,5]	[3,4]	[3,4]	[4,5]	[3,4]	[2,3]	[4,5]	[4,5]	[3,4]	[2,3]	[2,3]	[3,4]	[3,4]	[3,4]	[4,5]
DM10	[3,4]	[3,4]	[4,5]	[4,5]	[3,4]	[2,3]	[4,5]	[2,3]	[2,3]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]
DM11	[4,5]	[4,5]	[3,4]	[3,4]	[4,5]	[4,5]	[3,4]	[4,5]	[1,2]	[2,3]	[3,4]	[3,4]	[4,5]	[2,3]	[2,3]	[4,5]
DM12	[2,3]	[3,4]	[4,5]	[2,3]	[2,3]	[3,4]	[4,5]	[4,5]	[2,3]	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]

Table 7. Whitenization values of grey Shannon entropy data

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
DM1	3.50	4.50	4.50	2.50	4.50	4.50	4.50	4.50	4.50	4.50	3.50	4.50	4.50	4.50	4.50	4.50
DM2	4.50	3.50	4.50	4.50	3.50	3.50	4.50	4.50	4.50	4.50	4.50	4.50	3.50	3.50	4.50	4.50
DM3	3.50	4.50	4.50	2.50	4.50	3.50	4.50	4.50	3.50	3.50	4.50	4.50	2.50	4.50	4.50	4.50
DM4	4.50	4.50	4.50	4.50	3.50	3.50	3.50	4.50	3.50	4.50	4.50	3.50	3.50	4.50	3.50	3.50

DM5	1.50	3.50	3.50	2.50	3.50	2.50	3.50	4.50	3.50	3.50	4.50	4.50	3.50	4.50	4.50	4.50
DM6	2.50	4.50	4.50	4.50	4.50	4.50	2.50	3.50	4.50	4.50	3.50	2.50	2.50	3.50	3.50	3.50
DM7	4.50	3.50	3.50	3.50	4.50	2.50	3.50	4.50	3.50	2.50	2.50	3.50	3.50	4.50	4.50	2.50
DM8	3.50	2.50	4.50	4.50	4.50	3.50	1.50	3.50	4.50	4.50	1.50	4.50	4.50	2.50	2.50	3.50
DM9	4.50	4.50	3.50	3.50	4.50	3.50	2.50	4.50	4.50	3.50	2.50	2.50	3.50	3.50	3.50	4.50
DM10	3.50	3.50	4.50	4.50	3.50	2.50	4.50	2.50	2.50	4.50	4.50	4.50	4.50	4.50	4.50	3.50
DM11	4.50	4.50	3.50	3.50	4.50	4.50	3.50	4.50	1.50	2.50	3.50	3.50	4.50	2.50	2.50	4.50
DM12	2.50	3.50	4.50	2.50	2.50	3.50	4.50	4.50	2.50	4.50	4.50	4.50	3.50	4.50	3.50	4.50

We then normalized the whitened-based (crisp data) decision matrix, and the resultant matrix is as shown in Table 8.

Table 8. Normalized data based on Whitenization values

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**
DM1	0.08	0.10	0.09	0.06	0.09	0.11	0.10	0.09	0.10	0.10	0.08	0.10	0.10	0.10	0.10	0.09
DM2	0.10	0.07	0.09	0.10	0.07	0.08	0.10	0.09	0.10	0.10	0.10	0.10	0.08	0.07	0.10	0.09
DM3	0.08	0.10	0.09	0.06	0.09	0.08	0.10	0.09	0.08	0.07	0.10	0.10	0.06	0.10	0.10	0.09
DM4	0.10	0.10	0.09	0.10	0.07	0.08	0.08	0.09	0.08	0.10	0.10	0.07	0.08	0.10	0.08	0.07
DM5	0.03	0.07	0.07	0.06	0.07	0.06	0.08	0.09	0.08	0.07	0.10	0.10	0.08	0.10	0.10	0.09
DM6	0.06	0.10	0.09	0.10	0.09	0.11	0.06	0.07	0.10	0.10	0.08	0.05	0.06	0.07	0.08	0.07
DM7	0.10	0.07	0.07	0.08	0.09	0.06	0.08	0.09	0.08	0.05	0.06	0.07	0.08	0.10	0.10	0.05
DM8	0.08	0.05	0.09	0.10	0.09	0.08	0.03	0.07	0.10	0.10	0.03	0.10	0.10	0.05	0.05	0.07
DM9	0.10	0.10	0.07	0.08	0.09	0.08	0.06	0.09	0.10	0.07	0.06	0.05	0.08	0.07	0.08	0.09
DM10	0.08	0.07	0.09	0.10	0.07	0.06	0.10	0.05	0.06	0.10	0.10	0.10	0.10	0.10	0.10	0.07
DM11	0.10	0.10	0.07	0.08	0.09	0.11	0.08	0.09	0.03	0.05	0.08	0.07	0.10	0.05	0.05	0.09
DM12	0.06	0.07	0.09	0.06	0.05	0.08	0.10	0.09	0.06	0.10	0.10	0.10	0.08	0.10	0.08	0.09

After that, entropy, differential, and final values were calculated and are as shown in Table 9.

Table 9. Obtained weights of grey Shannon entropy method

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
E_J	0.022	0.012	0.009	0.018	0.012	0.014	0.022	0.011	0.022	0.014	0.022	0.014	0.013	0.014	0.014	0.012
d_J	0.978	0.988	0.991	0.982	0.988	0.986	0.978	0.989	0.978	0.986	0.978	0.986	0.987	0.986	0.986	0.988
w_J	0.0892	0.0477	0.0356	0.0735	0.0475	0.0587	0.0892	0.0451	0.0892	0.0578	0.0913	0.0578	0.0544	0.0578	0.0575	0.0475

Phase III: Ranking suppliers using grey EDAS method

After determining the criteria weights (Table 9), we used EDAS for ranking and selecting the optimal suppliers.

In step 2 of EDAS, through panel interview, the grey decision matrix was populated based on Equation (8) and further whitened using Equation (5). The results are as shown in Tables 10 and 11.

Table 10. Grey data as the inputs of the EDAS method

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Supplier 1	[3,4]	[4,5]	[4,5]	[2,3]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[4,5]	[3,4]	[3,4]	[4,5]	[4,5]	[4,5]	[4,5]
Supplier 2	[1,2]	[3,4]	[3,4]	[3,4]	[2,3]	[2,3]	[3,4]	[4,5]	[3,4]	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[4,5]	[4,5]
Supplier 3	[3,4]	[2,3]	[3,4]	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]	[1,2]	[1,2]	[2,3]	[4,5]	[2,3]	[2,3]	[3,4]
Supplier 4	[4,5]	[4,5]	[3,4]	[3,4]	[4,5]	[3,4]	[2,3]	[4,5]	[4,5]	[3,4]	[2,3]	[2,3]	[3,4]	[3,4]	[4,5]	[4,5]
Supplier 5	[3,4]	[3,4]	[4,5]	[4,5]	[3,4]	[2,3]	[4,5]	[2,3]	[2,3]	[4,5]	[4,5]	[4,5]	[3,4]	[4,5]	[4,5]	[3,4]
Supplier 6	[2,3]	[4,5]	[3,4]	[3,4]	[4,5]	[4,5]	[3,4]	[4,5]	[3,4]	[2,3]	[3,4]	[3,4]	[4,5]	[3,4]	[2,3]	[4,5]
Supplier 7	[1,2]	[3,4]	[4,5]	[2,3]	[2,3]	[3,4]	[2,3]	[2,3]	[4,5]	[2,3]	[2,3]	[4,5]	[3,4]	[4,5]	[3,4]	[4,5]

Table 11. Whitenization values of grey EDAS data

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Supplier 1	3.5	4.5	4.5	2.5	4.5	4.5	4.5	4.5	4.5	4.5	3.5	3.5	4.5	4.5	4.5	4.5
Supplier 2	1.5	3.5	3.5	3.5	2.5	2.5	3.5	4.5	3.5	4.5	4.5	4.5	3.5	4.5	4.5	4.5
Supplier 3	3.5	2.5	3.5	4.5	4.5	3.5	4.5	3.5	4.5	1.5	1.5	2.5	4.5	2.5	2.5	3.5
Supplier 4	4.5	4.5	3.5	3.5	4.5	3.5	2.5	4.5	4.5	3.5	2.5	2.5	3.5	3.5	4.5	4.5
Supplier 5	3.5	3.5	4.5	4.5	3.5	2.5	4.5	2.5	2.5	4.5	4.5	4.5	3.5	4.5	4.5	3.5
Supplier 6	2.5	4.5	3.5	3.5	4.5	4.5	3.5	4.5	3.5	2.5	3.5	3.5	4.5	3.5	2.5	4.5
Supplier 7	1.5	3.5	4.5	2.5	2.5	3.5	2.5	2.5	4.5	2.5	2.5	4.5	3.5	4.5	3.5	4.5

In the third step, using Equation (9), the average solution values were computed and are as shown in Table 12:

Table 12: Average solution values for all suppliers

Suppliers	$AV_{\otimes}$
Supplier 1	4.1825
Supplier 2	3.6875
Supplier 3	3.3125
Supplier 4	3.75
Supplier 5	3.8125
Supplier 6	3.6875
Supplier 7	3.3125

In step 4 of the EDAS method, the positive and negative distances matrices were computed from the average solution based on the kind of criteria. The values of $PDA_{ij\otimes}$ (positive distances) and $NDA_{ij\otimes}$ (negative distances) can be seen in Tables 13 and 14.

Table 13. $PDA_{ij\otimes}$ values for all suppliers

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Sup 1	0.000	0.189	0.145	0.000	0.189	0.286	0.189	0.189	0.145	0.340	0.089	0.039	0.145	0.145	0.000	0.068
Sup 2	0.488	0.000	0.000	0.000	0.000	0.000	0.000	0.189	0.000	0.340	0.400	0.000	0.000	0.145	0.000	0.068
Sup 3	0.000	0.000	0.000	0.286	0.189	0.000	0.189	0.000	0.145	0.000	0.000	0.314	0.145	0.000	0.340	0.000
Sup 4	0.000	0.189	0.000	0.000	0.189	0.000	0.000	0.189	0.145	0.043	0.000	0.314	0.000	0.000	0.000	0.068
Sup 5	0.000	0.000	0.145	0.286	0.000	0.000	0.189	0.000	0.000	0.340	0.400	0.000	0.000	0.145	0.000	0.000

Sup 6	0.146	0.189	0.000	0.000	0.189	0.286	0.000	0.189	0.000	0.000	0.089	0.039	0.145	0.000	0.340	0.068
Sup 7	0.488	0.000	0.145	0.000	0.000	0.000	0.000	0.000	0.145	0.000	0.000	0.000	0.000	0.145	0.075	0.068

Table 14. $\mathbf{NDA_{ij\otimes}}$ **values for all suppliers**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Sup 1	0.195	0.000	0.000	0.286	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.189	0.000
Sup 2	0.000	0.075	0.109	0.000	0.340	0.286	0.039	0.000	0.109	0.000	0.000	0.235	0.109	0.000	0.000	0.000
Sup 3	0.195	0.340	0.109	0.000	0.000	0.000	0.000	0.075	0.000	0.553	0.533	0.000	0.000	0.364	0.189	0.169
Sup 4	0.537	0.000	0.109	0.000	0.000	0.000	0.314	0.000	0.000	0.000	0.222	0.000	0.109	0.109	0.189	0.000
Sup 5	0.195	0.075	0.000	0.000	0.075	0.286	0.000	0.340	0.364	0.000	0.000	0.235	0.109	0.000	0.000	0.169
Sup 6	0.000	0.000	0.109	0.000	0.000	0.000	0.039	0.000	0.109	0.255	0.000	0.000	0.000	0.109	0.000	0.000
Sup 7	0.000	0.075	0.000	0.286	0.340	0.000	0.314	0.340	0.000	0.255	0.222	0.235	0.109	0.000	0.000	0.000

In the next step, the weights obtained through grey Shannon entropy method were multiplied through $\mathrm{PDA}_{ij\otimes}$ and $\mathrm{NDA}_{ij\otimes}$ values to achieve $SP_{i\otimes}$ and $SN_{i\otimes}$ values and are presented in Tables 15 and 16.

Table 15. $\mathbf{SP_{i\otimes}}$ **values for all suppliers**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Sup 1	0.000	0.009	0.005	0.000	0.009	0.017	0.017	0.009	0.013	0.020	0.008	0.002	0.008	0.008	0.000	0.003
Sup 2	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.020	0.037	0.000	0.000	0.008	0.000	0.003
Sup 3	0.000	0.000	0.000	0.021	0.009	0.000	0.017	0.000	0.013	0.000	0.000	0.018	0.008	0.000	0.020	0.000
Sup 4	0.000	0.009	0.000	0.000	0.009	0.000	0.000	0.009	0.013	0.002	0.000	0.018	0.000	0.000	0.000	0.003
Sup 5	0.000	0.000	0.005	0.021	0.000	0.000	0.017	0.000	0.000	0.020	0.037	0.000	0.000	0.008	0.000	0.000
Sup 6	0.013	0.009	0.000	0.000	0.009	0.017	0.000	0.009	0.000	0.000	0.008	0.002	0.008	0.000	0.020	0.003
Sup 7	0.044	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.008	0.004	0.003

Table 16. $\mathbf{SN_{i\otimes}}$ **values for all suppliers**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Sup 1	0.017	0.000	0.000	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000
Sup 2	0.000	0.004	0.004	0.000	0.016	0.017	0.003	0.000	0.010	0.000	0.000	0.014	0.006	0.000	0.000	0.000
Sup 3	0.017	0.016	0.004	0.000	0.000	0.000	0.000	0.003	0.000	0.032	0.049	0.000	0.000	0.021	0.011	0.008

Sup 4	0.048	0.000	0.004	0.000	0.000	0.000	0.028	0.000	0.000	0.000	0.020	0.000	0.006	0.006	0.011	0.000
Sup 5	0.017	0.004	0.000	0.000	0.004	0.017	0.000	0.015	0.032	0.000	0.000	0.014	0.006	0.000	0.000	0.008
Sup 6	0.000	0.000	0.004	0.000	0.000	0.000	0.003	0.000	0.010	0.015	0.000	0.000	0.000	0.006	0.000	0.000
Sup 7	0.000	0.004	0.000	0.021	0.016	0.000	0.028	0.015	0.000	0.015	0.020	0.014	0.006	0.000	0.000	0.000

After that, in the sixth step, SP_i and SN_i values were normalized are shown in Tables 17 and 18 as NSP_i and NSN_i:

Tables 17. $\mathbf{NSP_{i\otimes}}$ **values for all suppliers**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Sup 1	0.0000	0.2068	0.1190	0.0000	0.2060	0.3854	0.3868	0.1956	0.2982	0.4522	0.1865	0.0521	0.1819	0.1932	0.0000	0.0740
Sup 2	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1956	0.0000	0.4522	0.8393	0.0000	0.0000	0.1932	0.0000	0.0740
Sup 3	0.0000	0.0000	0.0000	0.4826	0.2060	0.0000	0.3868	0.0000	0.2982	0.0000	0.0000	0.4167	0.1819	0.0000	0.4488	0.0000
Sup 4	0.0000	0.2068	0.0000	0.0000	0.2060	0.0000	0.0000	0.1956	0.2982	0.0565	0.0000	0.4167	0.0000	0.0000	0.0000	0.0740
Sup 5	0.0000	0.0000	0.1190	0.4826	0.0000	0.0000	0.3868	0.0000	0.0000	0.4522	0.8393	0.0000	0.0000	0.1932	0.0000	0.0000
Sup 6	0.3000	0.2068	0.0000	0.0000	0.2060	0.3854	0.0000	0.1956	0.0000	0.0000	0.1865	0.0521	0.1819	0.0000	0.4488	0.0740
Sup 7	1.0000	0.0000	0.1190	0.0000	0.0000	0.0000	0.0000	0.0000	0.2982	0.0000	0.0000	0.0000	0.0000	0.1932	0.0997	0.0740

Tables 18. $\mathbf{NSN_{i\otimes}}$ **values for all suppliers**

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Sup 1	0.6426	1.0000	1.0000	0.5687	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7772	1.0000
Sup 2	1.0000	0.9261	0.9202	1.0000	0.6687	0.6556	0.9282	1.0000	0.8002	1.0000	1.0000	0.7207	0.8781	1.0000	1.0000	1.0000
Sup 3	0.6426	0.6673	0.9202	1.0000	1.0000	1.0000	1.0000	0.9301	1.0000	0.3434	0.0000	1.0000	1.0000	0.5684	0.7772	0.8347

Sup4	0.0170	1.0000	0.9202	1.0000	1.0000	1.0000	0.4253	1.0000	1.0000	1.0000	0.5833	1.0000	0.8781	0.8705	0.7772	1.0000
Sup5	0.6426	0.9261	1.0000	1.0000	0.9264	0.6556	1.0000	0.6854	0.3339	1.0000	1.0000	0.7207	0.8781	1.0000	1.0000	0.8347
Sup6	1.0000	1.0000	0.9202	1.0000	1.0000	1.0000	0.9282	1.0000	0.8002	0.6969	1.0000	1.0000	1.0000	0.8705	1.0000	1.0000
Sup7	1.0000	0.9261	1.0000	0.5687	0.6687	1.0000	0.4253	0.6854	1.0000	0.6969	0.5833	0.7207	0.8781	1.0000	1.0000	1.0000

Finally, in Step 7, the appraisal scores for all suppliers were computed and are showed in Table 19.

Table 19: Appraisal scores for all suppliers

Suppliers	AS_i	Rankings
Supplier 1	0.311280688	6
Supplier 2	0.96878	*1*
Supplier 3	0.321280688	5
Supplier 4	0.008521892	7
Supplier 5	0.351280688	4
Supplier 6	0.65	3
Supplier 7	0.932154	2

Based on the obtained the appraisal scores (ASC), suppliers were prioritized as follows:

$$Supplier2 > Supplier7 > Supplier6 > Supplier5 > Supplier3 > Supplier1 > Supplier4$$

4.3 Discussion of results and managerial implications

The final results can be found in Tables 9 and 19. The findings in Table 9 indicate that the four top-ranked criteria which include warranty level and experience time, relationship closeness, supplier's technical level, and risks are considered as the most important and influential criteria for supplier evaluation in the Iranian oil and gas industry and require more attention by the managers of the studied companies when measuring the aftermath selection performance of the optimal supplier over time. Considering the fact that today's Iranian industries face many challenges due to the imposed sanctions (Alipour et al., 2017), accurate selection of suppliers and over time, their performance evaluation in the Iranian oil and gas industry seems very vital for securing the Iranian economy which entirely relies on selling of crude oil and exporting the gas.

The results in Table 19 demonstrate that, of the seven suppliers of the oil and gas industry, supplier 2 has the highest importance priority whereas supplier 4 has the least important priority. It means that overall supplier 2 is recommended as the best/optimal supplier for cooperation/partnership by the case company and companies in the oil and gas industry for the supply of materials and services. On the other hand, supplier 4 should be considered as the last option by any company in the oil and gas industry seeking to work with any of the suppliers for any services or partnership/cooperation due to its weak performance overall. If this company (supplier 4) tends to improve its performance, it has to benchmark supplier 2 to be among the best practicing suppliers' in the Iranian oil and gas industry.

Notably, the managers and decision-makers in the studied oil and gas industry should be careful when attempting to collaborate with suppliers 3, 1 and 4 with the 5th, 6th, and 7th ranking positions respectively. It would be more beneficial if the managers concentrate their future cooperation with suppliers 2, 7 and 6. On the other hand, the managers of the lower ranked suppliers may rethink their operations to enhance their performance for future potential collaborations.

5. Sensitivity analysis

Sensitivity analysis was performed on the final results (supplier rankings) to check the robustness of the proposed approach and omit any possible biases. For this purpose, the sensitivity analysis method previously utilized by Mangla et al. (2015) and Gupta & Barua (2017) was also adopted in this study. In this regard, the objective of this sensitivity analysis was to figure out if the grey relational coefficient, α, (which was previously mentioned in Equation (5)) changes, what would be the resultant effect on the final ranking results. All the computations of this study were based on α=0.5. Thus, α from 0.1 to 0.9 is used and re-ran the model. The results are shown in Figure 2 and Table 20.

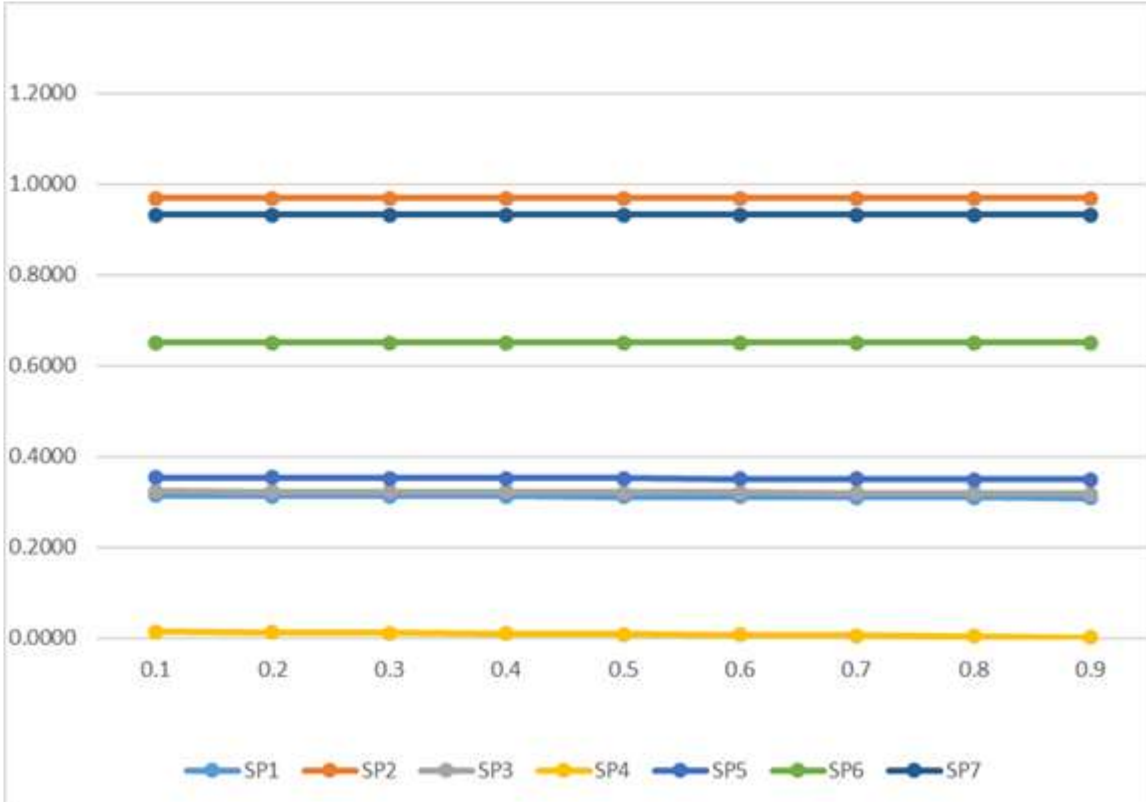

Figure 2. Sensitivity analysis of suppliers ranking based on different grey relational coefficients

Table 20. Variation of grey relational coefficient for observing changes in suppliers ranking

Grey coefficient (α)	Run 1 (0.1)	Run 2 (0.2)	Run 3 (0.3)	Run 4 (0.4)	Run 5 (0.5)	Run 6 (0.6)	Run 7 (0.7)	Run 8 (0.8)	Run 9 (0.9)
Sup 1	0.3132	0.3128	0.3123	0.3118	0.3113	0.3107	0.3101	0.3095	0.3088
Sup 2	0.9688	0.9688	0.9688	0.9688	0.9688	0.9688	0.9688	0.9688	0.9688
Sup 3	0.3232	0.3228	0.3223	0.3218	0.3213	0.3207	0.3201	0.3195	0.3188
Sup 4	0.0138	0.0126	0.0113	0.0100	0.0085	0.0070	0.0053	0.0035	0.0016
Sup 5	0.3532	0.3528	0.3523	0.3518	0.3513	0.3507	0.3501	0.3495	0.3488
Sup 6	0.6500	0.6500	0.6500	0.6500	0.6500	0.6500	0.6500	0.6500	0.6500
Sup 7	0.9322	0.9322	0.9322	0.9322	0.9322	0.9322	0.9322	0.9322	0.9322

As shown in Figure 2 and Table 20, the results based on each α, vary in reasonable and little amounts. The findings also demonstrated that suppliers 2 and 6 have fix results and do not have any changes with different coefficients. Other results have fluctuations of 0.01 tolerance.

6. Concluding remarks

Supplier selection has become one of the most popular topics in the SCM discipline research. Among the existing works, there are many studies in which the researchers have devoted their attention to this subject matter in the various journals. Many methods including MCDM methods have been applied for supplier evaluation and selection. In this paper, we attempted to show a distinct method for finding optimal supplier based on some relevant criteria. The first aspect of this research focused on identifying some important criteria relevant for supplier evaluation and selection. It was achieved through the review of literature of previous studies and preliminary discussions with decision-makers. It resulted in an initial 21 criteria. These initial criteria were further refined and focused to suit the Iranian oil and gas industry content aided by the grey-Delphi method.

Following the grey-Delphi method, a questionnaire based on the criteria and a five-point linguistic with equivalent grey interval number scales were designed and distributed among the 12 decision-makers. These decision-makers were selected from among the top managers of Iranian oil and gas companies with over 25years working experience. The responses received from the 12 decision-makers were evaluated and the criteria that did meet or exceed the 3.5 threshold value agreed among the researchers were maintained, otherwise eliminated. Five criteria including TQM; geographic location; corporate social responsibility; greenhouse gas emission; and demand were eliminated with remaining 16 criteria considered most relevant and important to the oil and gas industry.

For supplier evaluation and selection, grey EDAS method was then applied. EDAS method, like any other decision matrix method, requires criteria importance weights to enable the computation and ranking of alternatives. These criteria importance weights were obtained using grey Shannon entropy. The procedures for calculation EDAS method mentioned in section 3.1 were then followed. The result indicated that, among the seven suppliers, suppliers 2 has the best performance based on the criteria and can be considered as optimal supplier recommended for cooperation by any company within the oil and gas industry. It is however advised that, since suppliers 3, 1 and 4 had the worst overall performances, companies within the oil and gas industries must be careful when considering partnering with them. Alternatively, they may be considered as the last option in a time of need.

The paper contributions in the following ways: (1) developed a unique framework for guiding supplier selection decision-making in the oil and gas industry; (2) introduced, integrated and developed a multistage multi-criteria decision aiding tool composed of grey system theory, Shannon-Entropy and EDAS method; and (3) investigated the framework within an emerging economy nations, Iran's oil and gas industry, advancing our understanding on the subject matter, more importantly, from an emerging economy nation perspective.

As mentioned before, the oil and gas industry has a crucial role in Iran's economy and identifying the best/optimal internal and external suppliers for providing and maintaining facilities are very important. Delay in extraction and refining of oil and gas can affect all aspects of the Iranian economy and society. This paper using real-world data has provided these companies with an approach to finding the best/optimal suppliers in the industry. Furthermore, the results of the study provide the suppliers with medium to low performances (supplier 3, 1 and 4) with benchmark supplier (supplier 1) to improve their operational practices to improve overall performances for better and future cooperation.

This research comes with some limitations. First, since industrial decision-makers were located in diverse cities, and Iran is a large country, accessibility to these decision-makers was quite challenging, and hence only a handful of them were sampled. Therefore, a generalization of the results of this study to another country may not be possible. Due to the homogeneity of the industrial decision-makers (i.e., with more than 25 years in the oil and gas industry), we can be certain about the concerns associated with making the Iranian oil and gas industry more promising and profitable through supplier selection and potentially, the global oil and gas industry. Another limitation is the computational structure. Decision-makers were not very well familiar with the methods, hence, completing the questionnaire was very difficult for them, and so we had to spend much time explaining each method and stage to them. It may cause the results to be a bit biased, probably towards those stages that the managers/decision-makers understood more clearly.

For future work, the proposed criteria framework of this study in the oil and gas industry can be investigated using other MCDM methods and compared the results to that of this research. In another context, the framework can also be applied in other industries using the same or other MCDMs and conducted a comparative analysis of the results. For instance, this framework can be applied in automobile, food, aviation, hospitality, healthcare, and other industries. In addition, researches can use other MCDM methods such as AHP (Chinese, Nardin, & Saro, 2011), DEMATEL (Kusi-Sarpong et al., 2016b), or other hybrid methods such as rough set and fuzzy TOPSIS (Kusi-Sarpong, Bai, Sarkis & Wang, 2015), Entropy and TOPSIS (Chauhan, Singh, Tiwari, Patnaik & Thakur, 2017), FAHP-based TOPSIS, VIKOR and ELECTRE (Sivaraja & Sakthivel, 2017), fuzzy QFD and TOPSIS (Akbaş & Bilgen, 2017), grey-DEMATEL, ANP and VIKOR (Çelikbilek & Tüysüz, 2016) to evaluate the supplier performance in oil and gas industry. This study is the first of its kind and set the stage for further and future research on supplier selection in the oil and gas industry from an emerging economy perspective. Broader and more empirical works are required in this industry.

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