International Journal of Industrial Engineering & Production Research June 2024 Vol. 35, No. 2: 1-25
DOI: 10.22068/ijiepr.35.2.2004

RESEARCH PAPER

A Hybrid Method using MODM and BWM for Supplier Assessment under Uncertainty

Amin Amini[1], Alireza Alinezhad[2*]& Davood Gharakhani[3]

Received 4 February 2024; Revised 10 April 2024; Accepted 30 May 2024;

ABSTRACT
The selection of a sustainable supplier is a multi-criteria decision-making issue that covers a range of criteria (quantitative-qualitative). Selecting the most eco-friendly suppliers requires balancing tangible and intangible elements that may be out of sync. The problem gets more complicated when volume discounts are taken into account, as the buyer needs to decide between two issues: 1) What are the best sustainable suppliers? 2) Which amount needs to be bought from each of the selected eco-friendly suppliers? In current study a combined attitude of best-worst method (BWM) ameliorated via multi-objective mixed integer programming (MOMIP) and rough sets theory is developed. The aim of this work is to contemporaneously ascertain the order quantity allocated to these suppliers in the case of multiple sourcing, multiple products with multiple criteria and with capacity constraints of suppliers and the number of suppliers to employ. In this situation, price reductions are offered by suppliers based on add up commerce volume, not on the amount or assortment of items acquired from them. Finally, a solution approach is proposed to solve the multi-objective model, and the model is demonstrated using a case study in Iran Khodro Company (IKCO). The results indicate that ISACO is the most sustainable supplier and the most orders are assigned to this supplier.

KEYWORDS: *Best-worst method (BWM); Multi-objective decision-making (MODM); Rough sets theory; Sustainable supplier selection (SSS); Volume discount.*

1. Introduction

Over the last few years, have seen increasing focus on the long-term impacts of environmental issues and social capital on economic development and the growth of companies [1]. Specifically, social issues such as poverty, disabilities, children's rights, women's rights, minorities, and environmental issues like the development of infrastructure to reduce water, air, and soil pollution, greenhouse gases, optimal resource utilization, and the use of clean energy have gained significant importance [2]. Today, in the modern world, organizations must be sustainable to have the capability to meet the needs of future generations. Since supply chain management considers responsible behavior in all stages and members of the supply chain, it has become an area influenced by environmental approaches and paradigms (such as lean, agile, green, resilient, sustainable, etc.) alongside rapid developments in knowledge [3]. Each of these approaches has contributed to new concepts in supply chain management. One of these approaches is sustainable supply chain, which has emerged in recent years. Today, competition for the development of sustainable supply chains has replaced traditional and conventional competitions among firms and companies [4].

Suppliers have a significant part to play in achieving sustainability within the industry, as key upstream partners of the supply chain. The primary step in ensuring that the supply chain is sustainable, based on sustainability indicators, should therefore be to select suppliers. Due to the

* **Corresponding author: Alireza Alinezhad**
alalinezhad@gmail.com

1. *Ph.D. Student in Industrial Management, Department of Industrial Management, Qazvin Branch, Islamic Azad University, Qazvin, Iran.*
2. *Associate Professor, Department of Industrial and Mechanical, Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran.*
3. *Assistant Professor, Department of Industrial Management, Qazvin Branch, Islamic Azad University, Qazvin, Iran.*

fact that different sustainability criteria and sub-criteria need to be taken into account when making decisions, procurement issues are becoming more complex. It is therefore a multicriteria decision-making problem for the selection of sustainability suppliers. Since the performance of each organization within a chain will directly or indirectly affect the performance of other parts of the chain and the overall chain, making the wrong decision in selecting sustainable suppliers imposes significant visible and invisible costs on all processes, loops, and chain organizations (the principle of the leather whip effect). It leads to uncertainty and lack of coordination throughout the supply chain, resulting in many negative consequences for companies and chain entities. Considering these issues and the cost-effectiveness and time-consuming nature of the sustainable supplier selection process on one hand, and the increasing capabilities of information and communication technologies on the other hand, and considering the need for flexible and rapid systems in decision-making in the face of social challenges and environmental concerns in today's world, this study aims to propose an appropriate and efficient model for selecting sustainable suppliers, given the complexities and various dimensions of sustainability criteria. In addition, it has been shown in this study that the development of a sustainable supply chain will take place under today's competition conditions when selecting the best possible sustainable suppliers for each connection. The results of this study can be beneficial in designing sustainable supply chains and dealing with conditions where supply chain organizations, in addition to economic goals, pursue environmental and social objectives. A number of research papers have recently focused the problem of sustainable supplier selection, and researchers have suggested various methodologies and mathematical models for this purpose. However, there is limited research that examines all three aspects of sustainability (economic, environmental, and social) in the context of sustainable supplier selection. Consequently, in this specific area there is a lack of research. The criteria and sub-criteria used in this study cover all three aspects of sustainability (economic, environmental, and social). Furthermore, given the prevailing conditions in today's societies and the increasing complexities in the world, models and methods that address the issue of sustainable supplier selection under uncertain environments and conditions of uncertainty have gained more importance. Since the subject of sustainable supplier selection has the characteristics of a multi-criteria decision-making problem, various models and methods have been proposed by researchers in this regard. Nevertheless, quantitative research on the topic of selecting sustainable suppliers under uncertainty is scarce, and this issue represents another research gap addressed in this study. Based on the views of company experts and a comprehensive literature review, sustainability criteria and sub-criteria have been chosen for evaluating and selecting suppliers during the initial phase. Subsequently, BWM (Best-Worst Method) is employed as an efficient MCDM technique to ascertain the weight value of the criteria and sub-criteria. This method was first introduced by Jafar Rezaei in 2015. We employ BWM as it necessitated a lesser number of pairwise comparisons in comparison to the AHP method. In this circumstance, the pairwise comparisons exhibit greater compatibility, resulting in more reliable outcomes [5]. BWM can be useful for making the right decisions in selecting sustainable suppliers but relies on the decision-maker's subjective judgment in determining the best and worst criteria and their relative importance (pairwise comparisons), which may reduce the accuracy of qualitative comparisons based on subjective judgment (consistency rate). By enhancing the Best-Worst Method with the theory of Rough Sets, which has gained wide application in the analysis of multi-criteria decision-making recently, qualitative judgment in comparisons can be made more precise, and errors in the pairwise comparisons process can be eliminated. The combination of the Best-Worst Method and Rough Sets, following the approach presented in this research, constitutes a new model and has not yet been applied to the selection of sustainable supplier problem. Only a few studies have used Rough Sets theory to improve and enhance the Best-Worst Method, mainly for supplier (not necessarily sustainable) selection. However, none of these studies has investigated the decision table approach and the concept of conditional entropy in Rough Sets theory. One of the advantages of the proposed method is modeling the uncertainty associated with personal assessments and eliminating the decision-maker's subjective judgment by using the decision table approach in Rough Sets theory. Furthermore, by employing the concept of conditional entropy in Rough Sets, the significance (importance) of criteria is calculated, and the selection of the best and worst criteria, as well as pairwise comparisons in the Best-Worst Method, is based on this calculation. With this proposed method, there is no longer a need for the decision-maker's subjective judgment in determining the best and worst criteria and their relative importance compared to other criteria. By employing this model, which is introduced for the first time for the development of the Best-Worst Method, the consistency rate of the BWM method becomes zero in all stages. This indicates that qualitative judgment in comparisons has become more accurate, and evaluation errors in the pairwise comparisons process have been eliminated. The development of the Best-Worst Method using Rough Sets theory, with the approach introduced in this research, is presented for the first time for determining criteria weights in multi-criteria decision-making problems, and its application to the sustainable supplier selection problem is entirely new. Finally, the SAW and TOPSIS methods are employed for evaluating and ranking the suppliers. In this research, after selecting suppliers based on sustainability criteria using the rough BWM and SAW/ TOPSIS methods (supplier sustainability weights are determined at this stage), In the second phase, a multi-objective mathematical model for optimal order allocation to selected suppliers is proposed, using the calculated sustainability weights as one of the inputs to this multi-objective model. In this situation, price reductions are offered by suppliers based on add up commerce volume, not on the amount or assortment of items acquired from them. This approach is not widely explored in research on sustainable supplier selection. An algorithm for solving the multi-objective model is presented using a case study in Iran Khodro Company, and the results are obtained through MATLAB software. The results indicate that ISACO is the most sustainable supplier and the most orders are assigned to this supplier.

The rest of this paper is arranged like this:
Section 2 cites the relevant literature for SSS. Section 3 covers the basis of the hybrid BWM method and rough set theory. Section 4 reflects the steps of multi-objective modeling. The type of research experiment design for multi-objective optimization as well as the results, findings and discussion about them are given in Section 5. Ultimately, Section 6 provides conclusions and future suggestions.

2. Literature Review

The recent studies conducted in the discussed topic are reviewed in this section. SSS and OA are topics to be considered in the literature review. At the end of this section, a research gap and contributions from this paper is set out.

2.1. Sustainable supplier selection (SSS) and order allocation (OA)

SSS and OA have been significant issues over the past decades. In this area, a large number of studies were published, for example: Alidaee and Kochenberger [6], Li et al. [7], Ho et al. [8], Mafakheri et al. [9], and Chai et al. [10]. The selection of the optimum supplier was presented with a number of criteria. Degraeve and Roodhoft [11] argued that only cost considerations should be taken into account when choosing a supplier. As time went by, it became clear that the cost criterion alone could not provide an adequate assessment of suppliers and other factors must be taken into account. In order to appraisal the supplier, Dickson [12] submitted 23 criteria. The criteria employed in suppliers' selection in the reports since 1966 to now were investigated by Weber Charles et al. [13]. They have shown that quality, cost and delivery time are the three most necessary criteria for selecting a supplier. According to Li et al. [7], the selection of suppliers is subject to uncertainty in terms of demand and price. A two-stage approach to SSS and OA has been introduced by Razmi and Rafiei [14]. In the first stage, suppliers shall be screened according to their qualitative features. Mixed-integer nonlinear programming (MINLP) is employed in the second stage to set up order quantities all through the planning period. A mathematical model was developed by Mendoza and Ventura [15] to determine an optimum inventory policy. In order to assess the effectiveness of an inventory system under control, this model has taken a power-of-two (POT) approach. Using dynamic programming, Mafakheri et al. [9] studied SSS and OA. Ghorbani et al. [16], in conjunction with the weighting based on strengths, weaknesses, opportunities and threats according to SWOT analysis, have used qualitative and quantitative criteria. Kannan et al. [17] have dealt with the SSS, and have employed a fuzzy attitude to the ranking of suppliers. Nazari-Shirkouhi et al. [18] have developed a two-level fuzzy model in which suppliers set multiple price levels for their goods. For SSS and OA, they used the fuzzy goal approach of a decision maker (DMFG). The problem of the supply chain, namely the dynamic selection of suppliers (DSSP), in which the values of these parameters change from one period to another, was considered by Ware et al. [19]. A heuristic algorithm for SSS and OA was proposed by Singh [20]. An integrated approach for SSS and OA has been demonstrated by Scott et al. [21]. They have suggested an integrated framework for multistakeholder, multi-supplier environment based on multiple stochastic criteria and a robust approach to solve this problem. Lee et al. [22] used a Decision Support System (DSS) method for selecting the best suppliers with superior quality.

Three objective functions were used by Jadidi et al. [23], namely price, rejection and lead time. In order to solve this model, they presented two approaches, and then compared them. Guo and Li [24] have set up a multi-level supply chain with wholesalers, retail groups and suppliers. They have looked at different prices, the order costs and lead time. The aim of this model was to select the supplier and best policy for coordination at all levels in the chain. In order to allocate orders, Kuo et al. [25] applied the rules of the Association for the ranking of suppliers and the artificial neural network.

Moghaddam [26] has proposed a model to select the most suitable suppliers using Pareto solutions for logistics networks. They recommended stochastic demands where a fuzzy method was used to solve this model. For SSS-OA problem, a stochastic programming model was developed by Sarrafha et al. [27], that they employed the fortification of suppliers (FOS) and suppliers' business continuity plans (SBCP) strategies to create flexibility in the level of suppliers. Govindan et al. [28], in which they answered a number of questions on this subject, looked at the past studies carried out with regard to assessing green suppliers. In the food sector, Amorim et al. [29] presented a mathematical model of SSS. A model for reducing risk by maximising cooperation between different stages of the supply chain using knowledge sharing was presented in Sodenkamp et al. [30]. PrasannaVenkatesan et al. [31], used a combined fuzzy analytic hierarchy process (AHP) approach for ranking suppliers and applying multi-objective particle swarms (MOPS) in SSS and OA to assess the risks. Hamdan et al. [32] studied a multi-period model for green SSS and OA in which he used a fuzzy TOPSIS (summarized for Technique for Order Preference by Similarity to Ideal Solution) approach for assigning the weights of the selected criteria. For SSS and OA, Cebi et al. [33] have used two stage fuzzy approach. For supplier appraisal under uncertainty, Keshavarz Ghorabaee et al. [34] employed environmental (environmental pollution) and economic factors. In order to evaluate suppliers, they applied two positive and negative functions in which fuzzy programming was employed. A multi-national decision model was studied by Noori-Daryan et al. [35] with constrained capacity for the producer and one retailer in which the demand was considered to be stochastic and depended on cost, delivery time, and lost sales, where the quality function deployment (QFD) method and stochastic programming were applied for order appraisal and allotment. The demand has been assumed to be stochastic in their model. Sustainability criteria for the evaluation of suppliers and multi-agent systems (MAS) were used by Ghadimi et al. [1] for the SSS-OA. Hamdan et al. [36] documented the problem of green SSS and OA, in relation to different availability of suppliers. For the choice of suppliers, they applied fuzzy TOPSIS and AHP. Hamdan et al. [37] analyzed the issue of Green SSS and OA, noting quantity discounts. The problem of SSS was presented by Vahidi et al. [38]. The authors used stochastic programming as well as a hybrid SWOT-QFD. Cheraghalipour and Farsad [2], in applying the BWM to determine supplier weightings, studied the problem of SSM and OA. They solved their model applying RMCGP (short for revised multi-choice goal programming) method. The integration of SSS-OA into a centralized supply chain with the risk of disruption has been suggested by Esmaeili-Najafabadi et al [39]. In order to mitigate the impact of disruption, they have used a protected supplier and a prepositioned emergency inventory strategy.

In the case of SSS and OA, Park et al [40] presented a two-phase approach in which the sustainable supplier regions are recognized first, followed by the implementation of the OA. For SSS, Lo et al. [41] have used a combination of BWM-TOPSIS. In order to solve the OA model, they used a fuzzy approach. To support the decision on when to apply both proactive and corrective strategies, Hosseini et al. [42] developed a stochastic bi-objective mixed-integer programming model for SSS. The approach proposed by Kellner and Utz [43] is to support purchasing managers in the liquidation of portfolios of midterm suppliers. A fuzzy goal programming model presented by Wong [44] focusing on the importance of a supplier portfolio and OA and pioneered the integration of a supplier's dynamic risk and green market segmentation in supplier selection problems. In order to effectively resolve the problem of SSS and OA, Jia et al. [45] have developed an optimization model that balances multiple conflicting objectives. Khoshfetrat et al. [46] studied SSS and OA with inflation, risk and fuzzy uncertainties. The model had six objective functions, which included total cost, economic performance, environmental score, social rating, inflation rate and level of risk. In the closed-loop supply chain, Nasr et al. [47] have proposed a novel two stage fuzzy supplier selection and OA model. For the selection of the most suitable suppliers and the fuzzy goal programming approach for solving the model, they applied the fuzzy BWM method. Li et al. [48], in order to dynamically select suppliers and determine the quantity of orders, developed a new two stage comprehensive algorithm. In order to examine the dynamic selection and organic agriculture problem, they have created green factors and supplier risks. Alinezhad [49] provided a multi-stage hybrid model for integrated supplier evaluation, selection and OA, remarking risks and disruptions. They used a data envelopment analysis (DEA) to assessment the suppliers. A hybrid model introduced by Cui et al. [50] that integrates fuzzy set theory, stepwise weight assessment ratio analysis, and a bayesian network for evaluating the critical SSS criteria in a multi-tier supply chain (MTSC). A MILP for SSS and OA was presented by Sontake et al. [51], focusing on the selection of transport alternatives for the delivery of goods. In order to investigate the SSS and OA problem, Beiki et al. [52] have developed a new combination of language entropy weight method (LEWM) with multi-objective programming (MOP) method. Aditi et al. [53] proposed a BWM-MARCOS model for SSS sand OA. Sharma and Darbari [54] provided an integrated optimization model for SSS and OA in the food supply chain. Gidiagba et al. [55] employed a hybrid Delphi-BWM-TOPSIS for SSS. Azizi and Shahrokhi [56] introduced a model applying COPRAS and interval type-2 fuzzy sets for dynamically selecting suppliers and determining an order quantity. Ratna et al. [57] presented a novel integration of grey relational analysis and TOPSIS to study a SSS and OA problem. Zhang et al. [58] developed a fuzzy entropy VIKOR model for SSS and OA.

2.2. Research gap

Numerous of publications have been carried out over the last years on SSS, and a variety of models and approaches are being suggested by researchers to this end. However, there is limited research that examines all three aspects of sustainability (economic, environmental, and social) in the context of SSS [4]. Therefore, there is a lack of research in this area. All three aspects of sustainability, economic, environmental, and social, are covered by the criteria and sub-criteria employed in this study. Furthermore, given the prevailing conditions in today's societies and the increasing complexities in the world, models and methods that address the issue of SSS under uncertain environments and conditions of uncertainty have gained more importance. Since the subject of SSS has the characteristics of a MCDM problem, various models and methods have been proposed by researchers in this regard. Nevertheless, quantitative research on the topic of selecting sustainable suppliers under uncertainty is scarce, and this issue represents another research gap addressed in this study.

The combination of the BWM and rough sets, following the approach presented in this research, constitutes a new model and has not yet been applied to the sustainable supplier selection problem. Only a few researchers have used rough sets theory to improve and enhance the BWM, mainly for supplier (not necessarily sustainable) selection. However, none of these studies has investigated the decision table approach and the concept of conditional entropy in rough sets theory.

The development of the BWM using rough sets theory, with the approach introduced in this research, is presented for the first time for determining criteria weights in MCDM problems, and its application to the selection of sustainable supplier problem is entirely new. In the proposed model in this research, which is a mixed-integer multi-objective programming model under multi-product, multi-source, and single-period conditions, one of the objective functions is related to maximizing supplier sustainability weights to ensure a higher allocation to sustainable suppliers. Additionally, the total procurement cost is minimized by decisions related to order allocation in this model. Separate objective functions are defined in this model to minimize the number of defective products supplied and maximize the number of on-time deliveries. The combination of limitations such as capacity, on-time delivery, disadvantages, and price, considering multi-product scenarios, taking into account supplier sustainability weights in order allocation (calculated using the rough BWM method in the first part of the research), and aggregating these factors make the current research unique.

In a final summary, Table 1 shows the background of the research in the field of SSS and OA.

Tab. 1. A short review of the literature on the selection of sustainable supplier and order allocation.

Reference	Year	BWM	Rough Sets Theory: Decision Table Approach	Rough Sets Theory: Conditional Entropy	Rough Sets Theory: Attribute Significance	OA	Sustainable Criteria: Economic	Sustainable Criteria: Social	Sustainable Criteria: Environmental	Solution Approach
[59]	2007		√	√	√	√	√			AHP, Rough sets theory, Mixed-integer programming
[16]	2012					√	√	√	√	SWOT analysis, Shannon entropy
[17]	2013					√	√		√	Fuzzy AHP, Fuzzy TOPSIS
[19]	2014					√	√			MINLP, Dynamic supplier selection problem
[20]	2014					√	√	√	√	TOPSIS, Mixed-integer linear programming (MILP)
[24]	2015					√	√			MINLP model
[27]	2014					√	√	√	√	Possibility programming, Two-stage stochastic programming
[29]	2016					√	√	√	√	Benders decomposition algorithm
[32]	2016					√	√	√	√	Fuzzy TOPSIS, AHP
[34]	2017					√	√		√	EDAS (Evaluation based on Distance from Average Solution) method, Interval type-2 fuzzy sets
[1]	2017					√	√	√	√	Multi-agent system approach
[38]	2018					√	√	√	√	ε -constraint method and metaheuristics
[41]	2018	√				√	√		√	BWM, Modified fuzzy TOPSIS, FMOLP
[2]	2018	√				√	√	√	√	Hybrid BWM-RMCGP
[43]	2019					√	√			Combining integer variables with Markowitz portfolio theory
[45]	2020	√				√	√	√	√	Distributionally robust goal programming model, Tractable approximation
[47]	2020	√				√	√			Fuzzy BWM, Fuzzy goal programming approach
[60]	2020	√					√			BWM, COCOSO, Interval rough boundaries
[61]	2020	√					√	√	√	New fuzzy approach based on BWM and α-cut
[49]	2019					√	√			DEA, Fuzzy AHP technique
[50]	2021						√ √	√		Bayesian network

[52]	2021					√	√	√	√	Novel integration of LEWM and MOP method
[62]	2019	√					√ √			BWM, Rough number
[54]	2021	√				√	√	√	√	BWM, Fuzzy sets theory
[53]	2022	√				√	√		√	BWM-MARCOS
[55]	2023	√					√ √	√		Delphi-BWM-TOPSIS
[56]	2023						√			COPRAS, Interval type-2 fuzzy sets
[57]	2023						√	√	√	Grey relational analysis, TOPSIS
[58]	2023						√	√	√	Fuzzy entropy VIKOR
This paper		√	√	√	√	√	√	√	√	BWM, Rough sets, Mixed integer programming

3. Improved BWM using Rough Sets Theory

3.1. Data table approach, conditional entropy and significance concept in rough set theory

Rough set theory was first introduced by Pawlak [63] in 1982 to express and investigate problems characterized by uncertainty and ambiguity, often used to discover inconsistencies and relationships in data. The key features of this theory include: 1) An optimal algorithm for finding patterns; 2) The ability to find relationships that are not discovered by statistical methods; 3) The ability to use both quantitative and qualitative information; 4) Identifying a minimal set of data that is useful for classification (e.g., reducing dimensionality and the amount of data); 5) Evaluating the significance of attributes (which is used in this research); 6) Generating decision rules from data [63].

Some important concepts in rough set theory are described as follows: In formal terms, the data table is a four-tuple $S = \langle U, R, V, f \rangle$ Eq. (1), where U is a limited set of objects; $R = C \cup D$ is a group of features (attributes), subsets C and D are the set of condition attribute and the set of decision attribute; V_r is attribute domain r, $V = \cup_{r \in R} V_r$ Eq. (2) and $f: U \times R \to V$ Eq. (3) is a generally function such that $f(x, r) \in V_r$ for each $r \in R$, $x \in U$, known as information function. To each subset which is non-empty B of attributes R $(B \subseteq R)$ is related to an intangibility relation on U, demonstrated by $\mathrm{IND}(B)$ in Eq. (4) [64]:

$$IND(B) = \left[(x,y) \middle| (x,y) \in U \times U, \forall b \in B(b(x) = b(y)) \right] \quad (4)$$

Thus, the intangible relation defined is an equidistant relation (i.e., symmetric, transitive and reflexive). The group of all the equidistant classes of the relation $IND(B)$ is demonstrated by $U \mid IND(B)$. Three other basic definitions in rough sets are as follows [64]:

- **Definition 1.** Based on Eq. (5), the entropy $H(P)$ of knowledge P (set of attributes) is specified. Where $p(X_i) = |X_i|/|U|$ and $p(X_i)$ denotes the probability of X_i when P is on the partition $X = \{X_1, X_2, \ldots, X_n\}$ of universe U, $i = 1, 2, \ldots, n$:

$$H(P) = -\sum_{i=1}^{n} p(X_i) \log_2 p(X_i) \quad (5)$$

- **Definition 2.** The entropy $H(Q|P)$ (that is conditional) which knowledge of $Q(U|\mathrm{IND}(Q) = \{Y_1, Y_2, \ldots, Y_m\})$ is relative to knowledge $P(U|\mathrm{IND}(P) = \{X_1, X_2, \ldots, X_n\})$ is defined based on Eq. (6). Where $p(Y_j|X_i)$ is conditional probability, $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$:

$$H(Q|P) = -\sum_{i=1}^{n} p(X_i) \sum_{j=1}^{m} p(Y_j|X_i) \log_2 p(Y_j|X_i) \quad (6)$$

- **Definition 3.** Consider the decision table $S = \langle U, R, V, f \rangle$, $R = C \cup D$, subsets C and D are the set of condition attribute and the set of decision attribute, subset of attribute $A \subset C$. The significance $SGF(a, A, D)$ of attribute a $(a \in C \setminus A)$ is specified based on Eq. (7). Given a subset of attributes A, the higher the value of $SGF(a, A, D)$, the more necessary attribute A is for decision D:

$$SGF(a, A, D) = H(D|A) - H(D|A \cup \{a\}) \quad (7)$$

3.2. Rough BWM approach

In 2015, Jafar Rezaei [5] first introduced a BWM to establish the weight of criteria in MCDM issues. In their research, the BWM method was compared to several other MCDM methods, including the AHP. Based on the results obtained, it was concluded that this method could be one of the most efficient methods available. In the BWM method, the decision maker identifies the best and the worst indicators and criteria, and pairs the two indicators, which are the best and the worst, with other indicators. Then, the problem is transformed into a linear programming problem in such a way that the weights of the indicators are determined so that the absolute differences in weights are minimized. This method requires fewer pairwise comparisons compared to the AHP method, and it also leads to more consistent pairwise comparisons and more reliable results [5].

In the BWM method, the decision-maker is asked to select and specify the best and worst criteria based on their subjective judgment. Therefore, the BWM method is fundamentally related to human judgment, and this aspect can affect its consistency. Additionally, in this method, a scale from 1 to 9 based on the preference of these criteria over others is used for pairwise comparisons between the best and worst criteria, and this also relates to human judgments. On the other hand, insufficient and incomplete information about alternatives and the existence of qualitative criteria in their evaluation make decision-making complex in selecting the ideal option. Hence, a theoretical need arises to create a powerful method for solving MCDM problems in the presence of uncertainty. For this purpose, and also to reduce the influence of human subjective judgment, the approach of decision tables in accordance with the theory of rough sets is proposed in this research aimed at attaining even more tangible weight values. Furthermore, entropy (conditional) and the concept of the significance of criteria in rough set theory are employed in the BWM method to enhance the evenness of judgments and resolve the problem of assessment errors in this method. The presented model in current study drives the consistency rate of the BWM method to zero and provides the most consistent results. Here are the main steps of the improved BWM method based on rough sets theory:

- *Step 1:* Ascertaining the decision criteria set.
- *Step 2:* Designing a decision table for the criteria.
- *Step 3:* Evaluating the decision column in the decision tables by an evaluation team.
- *Step 4:* Computing the significance and importance of criteria using the decision tables and Eqs. (1) to (7).
- *Step 5:* Selecting the best and worst criteria based on the calculated SGF for each criterion in the previous step. In this step, the best and worst criteria are determined based on the importance and significance calculated (SGF) using rough sets equations, not by mental selection.
- *Step 6:* Making pairwise comparisons between the best criterion and the other criteria. In this step, a scale from 1 to 9 is not used for the preference of the best criterion over others. Instead, the preference of the best criterion (B) over other criteria (j) is calculated using Eq. (8), and the best-to-others vector is constructed as $A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$:

$$a_{Bj} = \frac{SGF_B}{SGF_j}, \quad a_{BB} = 1 \quad (8)$$

- *Step 7:* Making pairwise comparisons between other criteria and the worst criterion. Again, a scale from 1 to 9 is not used for the preference of other criteria over the worst criterion. Instead, the preference of other criteria (j) over the worst criterion (W) is calculated using Eq. (9), and the others-to-worst vector is constructed as $A_W = (a_{1W}, a_{2W}, \dots, a_{nW})$:

$$a_{jW} = \frac{SGF_j}{SGF_W}, \quad a_{WW} = 1 \quad (9)$$

- *Step 8:* Determine the weights of the criteria. In this step, the weights of the criteria are determined using an optimization model according to Eq. (10) [42]. This model can be implemented and solved using software like Lingo:

$$Min\ Max\left(\left|\frac{W_B}{W_j} - a_{Bj}\right|, \left|\frac{W_j}{W_W} - a_{jW}\right|\right)$$
$$Subject\ to:$$
$$\sum_j W_j = 1$$
$$W_j \geq 0\ for\ all\ j, j = 1,2,\dots,n \quad (10)$$

Also, Eq. (10) can be modeled as Eq. (11) [42]:

$$\begin{aligned}
&Min\ \varepsilon \\
&Subject\ to: \\
&\left|\frac{W_B}{W_j} - a_{Bj}\right| \leq \varepsilon \quad , \quad j = 1,2,\dots,n \\
&\left|\frac{W_j}{W_W} - a_{jW}\right| \leq \varepsilon \quad , \quad j = 1,2,\dots,n \\
&\sum_j W_j = 1 \\
&W_j \geq 0 \quad , \quad for\ all\ j \qquad (11)
\end{aligned}$$

- *Step 9:* Once optimal weights are obtained, the consistency of comparisons should be assessed. The consistency level is calculated using Eq. (12) [43]. The closer the compatibility values are to zero, the more compatible the results.

$$Consistency\ Ratio = \frac{\varepsilon^*}{Consistency\ Index} \quad (12)$$

In the proposed model of this study, the value ε^* obtained from solving Eq. (11) is always equal to zero, so the consistency level in this method is always zero, and using this model provides the most consistent results.

3.3. Solving the sustainable supplier selection problem using proposed rough BWM model

In this paper, the problem of selecting a stable supplier for IKCO is presented. This company can obtain its required goods from several suppliers. The active group of suppliers for IKCO in this study includes IRANCO, ISACO, SAPCO, and MCPCO. To achieve this, it is necessary to prioritize the suppliers to determine the order of purchasing goods from them. In this research, all three sustainability aspects, which encompass economic, social, and environmental criteria, have been considered for evaluating the suppliers. Then, using the proposed rough BWM method, the weights of criteria and sub-criteria have been determined. Finally, by employing the simple additive weighting (SAW) method, the scores of suppliers have been calculated, and appropriate prioritization for purchasing goods has been established. It is worth noting that each supplier can supply all the required goods for the company. The basis stage of the presented model is illustrated in Figure 1 and are described as follows: 1) Identification and definition of criteria for the selection of sustainable supplier issue; 2) Calculation of the weights of criteria and sub-criteria using the rough BWM method (detailed in the previous section); 3) Calculation of the general score for suppliers using the TOPSIS and SAW methods.

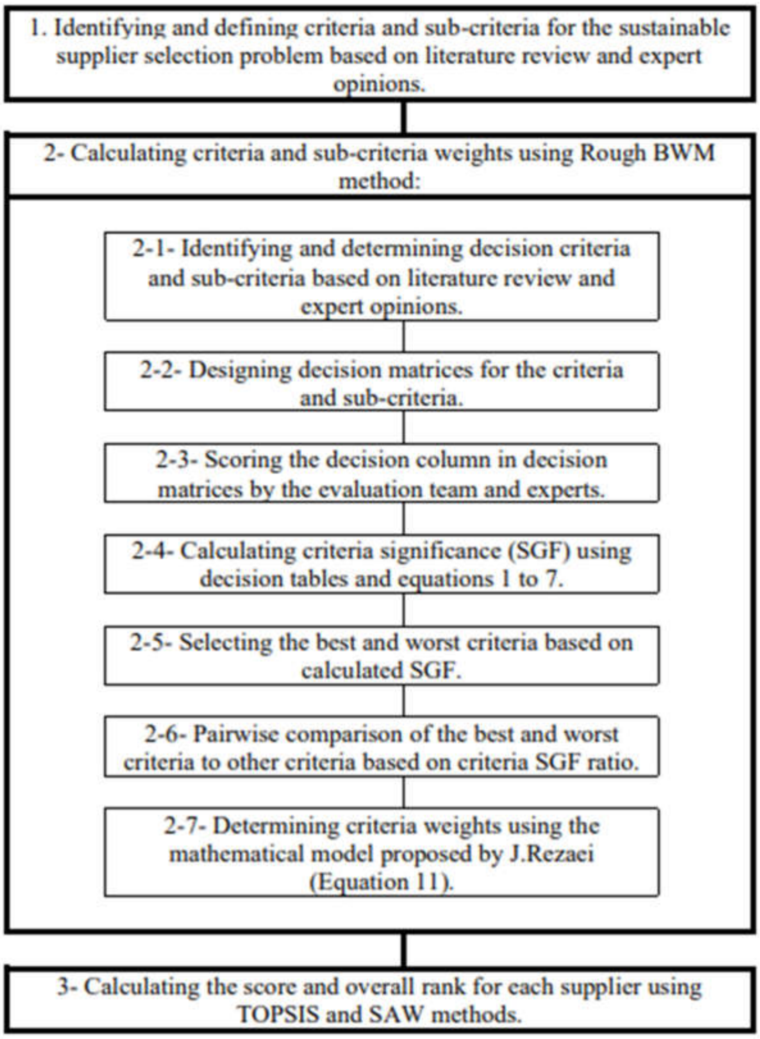

Fig. 1. The framework of proposed model.

3.3.1. Identification and definition of criteria for the selection of sustainable supplier

To evaluate and select a sustainable insurance supplier based on sustainability aspects, several criteria and sub-criteria have been selected based on previous studies and have been studied and approved by IKCO's experts. The selected criteria and sub-criteria for current research are detailed in Table 2.

According to the multitude of factors influencing the decision-making process for selecting a sustainable insurance supplier, decisions should be made through a hierarchical sequence of these stages. In fact, the majority of companies are unable to take into account a number of factors at once when making decisions. Therefore, this complex problem should be decomposed into controllable sub-issues via a multi-level decision-making hierarchy. This study made a 4-level hierarchy structure, where the highest level reflects the problem's objective (selecting a sustainable insurance supplier for IKCO), and the bottom level includes different insurance suppliers of IKCO (IRANCO, ISACO, SAPCO, and MCPCO). The second level of this structure includes sustainability criteria, which are typically considered when selecting a sustainable insurance supplier. These criteria include economic, social, and environmental aspects. These criteria are further divided into different sub-criteria which may affect the choice of a sustainable insurance provider at the third level. The overall hierarchy used in this research is shown in Figure 2.

Tab. 2. Criteria and sub-criteria for sustainable supplier selection in current research.

Criteria	Sub-criteria	Reference
Economic	Price	Ratna et al. [57]
	Defects	Vahidi et al. [38]
	Technical level	Xia and Wu [59]
	Supply capacity	Cui et al. [50]
Environmental	Resource consumption	Azizi and Shahrokhi [56]
	Environment pollution	Zhang et al. [58]
	Environment management system	Zhang et al. [60]
Social	On-time delivery	Aditi et al. [53]
	Warranty period	Gidiagba et al. [55]
	Repair turn round time	Alinezhad. [62]
	Employee satisfaction	Beiki et al. [52]

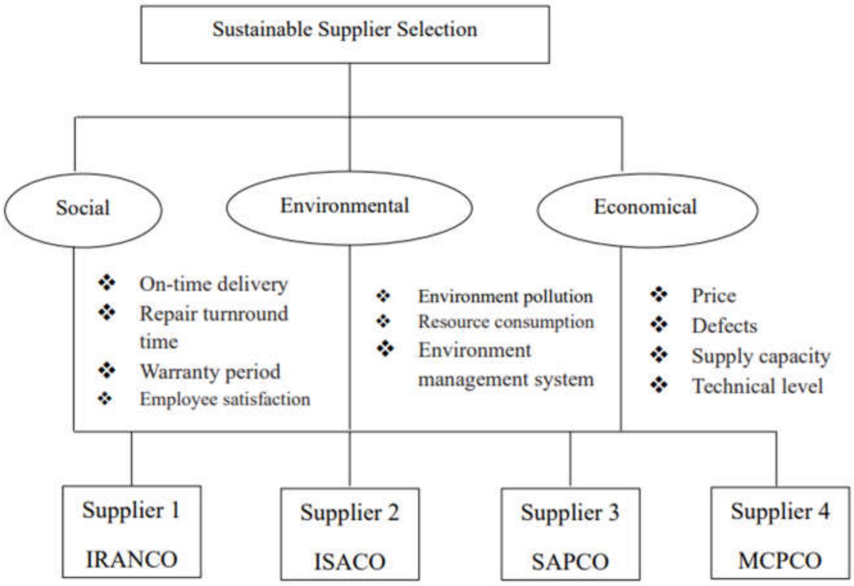

Fig. 2. The hierarchy of selection of sustainable supplier.

3.3.2. Calculation of criteria and sub-criteria weights using rough BWM

For the second level of Figure 2, it is possible to create a table of decision such as Table 3, which does not contain values from column "Decision", for appraisal teams to make decisions on column "Decision". First of all, the economic, social and environmental criteria (or attributes) are ranked by the three-point scale, including the values of 1, 2 and 3 which are related with "good", "middle" and "poor", respectively, for economic, social and environmental criteria. Second, before the evaluation process we can create a table that lists different integrations of criterion values. We have 14 different combinations listed in Table 3. The assessment team shall then be given a table to make its decision. The number "1" in "decision" column reflects "the supplier is selected" and the number "0" reflects "the supplier is not selected". For example, a combination of the 2nd line in row 2 indicates that if the economy is weak but social and environmental conditions are good for the supplier, it will not be chosen. The following process based on Eqs. (13) to (22) can give us criteria of economic, social and environmental importance for the decision table in Table 3. The SGF of attribute a (economic criterion) is calculated, resulting in a value of 0.1882. Similarly, through the same process, the significance of attribute b (social criterion) is found to be 0.1022, and the significance of attribute c (environmental criterion) is 0.1452. Based on the calculated significances for the three criteria, attribute a (economic) is the best criterion, and attribute b (social) is the worst criterion. According to Eq. (8), the vector "Best Compared to Others" is formed as Eq. (23) and Eq. (24). Similarly, according to Eq. (9), the vector "Others Compared to Worst" is formed as Eq. (25) and Eq. (26). The summary of the best-worst results is shown in Table 4 and Table 5.

Tab. 3. Economic, social and environmental decision table.

U	Economic (a)	Social (b)	Environmental (c)	Decision (d)
1	2	1	1	1
2	3	1	1	0
3	1	2	2	1
4	2	2	2	1
5	3	2	1	0
6	1	2	3	0
7	1	3	1	0
8	1	1	3	1
9	2	2	1	1
10	2	2	3	0
11	3	3	1	0
12	3	2	2	0
13	2	3	1	0
14	2	1	3	0

Tab. 4. The pairwise comparison vectors for the best criterion compared with the others.

Criteria	a	b	c
Best criterion: a	1	1.8415	1.2961

Tab. 5. The pairwise comparison vectors for other criteria compared to the worst criterion.

Criteria	Worst criterion: b
a	1.8415
b	1
c	1.4207

$$U \left| IND\{a,b,c\} \right. = \left\{ \begin{array}{l} \{1\},\{2\},\{3\},\{4\},\{5\}, \\ \{6\},\{7\},\{8\},\{9\}, \\ \{10\},\{11\},\{12\},\{13\},\{14\} \end{array} \right\} \qquad (13)$$

$$U \left| IND\{d\} \right. = \{\{2,5,6,7,10,11,12,13,14\},\{1,3,4,8,9\}\} = \{Y_1,Y_2\} \qquad (14)$$

$$U \left| IND\{b,c\} \right. = \left\{ \begin{array}{l} \{1,2\},\{3,4,12\},\{5,9\},\{6,10\}, \\ \{7,11,13\},\{8,14\} \end{array} \right\} = \{X_1,X_2,X_3,X_4,X_5,X_6\} \qquad (15)$$

$$p(X_1) = \frac{2}{14} \;,\; p(Y_1 \left| X_1 \right.) = \frac{1}{2} \;,\; p(Y_2 \left| X_1 \right.) = \frac{1}{2} \qquad (16)$$

$$p(X_2) = \frac{3}{14} \;,\; p(Y_1 \left| X_2 \right.) = \frac{1}{3} \;,\; p(Y_2 \left| X_2 \right.) = \frac{2}{3} \qquad (17)$$

$$p(X_3) = \frac{2}{14} \;,\; p(Y_1 \left| X_3 \right.) = \frac{1}{2} \;,\; p(Y_2 \left| X_3 \right.) = \frac{1}{2} \qquad (18)$$

$$p(X_4) = \frac{2}{14} \;,\; p(Y_1 \left| X_4 \right.) = 1 \;,\; p(Y_2 \left| X_4 \right.) = 0 \qquad (19)$$

$$p(X_5) = \frac{3}{14} \;,\; p(Y_1 \left| X_5 \right.) = 1 \;,\; p(Y_2 \left| X_5 \right.) = 0 \qquad (20)$$

$$p(X_6) = \frac{2}{14} \;,\; p(Y_1 \left| X_6 \right.) = \frac{1}{2} \;,\; p(Y_2 \left| X_6 \right.) = \frac{1}{2} \qquad (21)$$

$$SGF(a,\{b,c\},\{d\}) = H(\{d\}\big|\{b,c\}) - H(\{d\}\big|\{a,b,c\})$$
$$= -\frac{2}{14}\left(\frac{1}{2}\log\frac{1}{2}+\frac{1}{2}\log\frac{1}{2}\right)\times 3 - \frac{3}{14}\left(\frac{1}{3}\log\frac{1}{3}+\frac{2}{3}\log\frac{2}{3}\right) = 0.1882 \quad (22)$$

$$a_{ab} = \frac{SGF_a}{SGF_b} = \frac{0.1882}{0.1022} = 1.8415 \quad (23)$$
$$a_{ac} = \frac{SGF_a}{SGF_c} = \frac{0.1882}{0.1452} = 1.2961 \quad (24)$$
$$a_{ab} = \frac{SGF_a}{SGF_b} = \frac{0.1882}{0.1022} = 1.8415 \quad (25)$$
$$a_{cb} = \frac{SGF_c}{SGF_b} = \frac{0.1452}{0.1022} = 1.4207 \quad (26)$$

Using Eq. (11) and referring to the pairwise comparison vectors tables (Table 4 and Table 5), the model for calculating the weights of sustainability criteria is presented as Eq. (27).

$$\begin{aligned} & Min\,\varepsilon \\ & Subject\,to: \\ & \left|\frac{W_a}{W_b} - 1.8415\right| \le \varepsilon \ , \ \left|\frac{W_a}{W_c} - 1.2961\right| \le \varepsilon \ , \\ & \left|\frac{W_c}{W_b} - 1.4207\right| \le \varepsilon \ , \ W_a + W_b + W_c = 1 \\ & W_a, W_b, W_c \ge 0 \qquad (27) \end{aligned}$$

This model is solved using the Lingo software, and the results are presented in Table 6:

Tab. 6. Economic, social and environmental computational results.

	Weights	ε^*
Economic (a)	0.4321	
Social (b)	0.2346	0
Environmental (c)	0.3333	

The value of ε^* is equal to zero, indicating perfect consistency, and the most consistent result has been achieved. In Table 7, values 1, 2, and 3 represent different meanings for the various sub-criteria described in Figure 1. Table 8 provides a decision table for prioritizing economic sub-criteria, including price, technical level, defects, and supply capacity (level 3 of Figure 1). Likewise, Table 9 presents a decision table for prioritizing environmental sub-criteria, including resource and energy consumption, environmental management system, and environmental pollution. Table 10 records decision-making for prioritizing social sub-criteria. Social sub-criteria include on-time delivery, warranty period, repair turnaround time, and employee satisfaction (level 3 of Figure 1).

The calculated results for the weights of economic, environmental and social sub-criteria are shown in Tables 11 to 13 by repeating Eqs. (13) to (27). The results obtained indicate that the consistency level in the BWM method using the proposed approach is zero in all stages. This suggests that the use of the proposed approach in this study improves consistency levels in the BWM method and provides the most consistent results.

3.3.3. Suppliers overall score computing

Considering the all-sub-criteria and criteria, as indicated in the "global weights" column of Table 14 global priority weights are established. Priority order of criteria is shown in the last column of Table 14. The highest ranking in the table can be seen for the price criterion.

The second position is occupied by the resource consumption sub-criterion in the environmental criterion, followed by the defects sub-criterion in the economic criterion. Suppose that four suppliers, IRANCO, ISACO, SAPCO, and MCPCO are involved in the appraisal process of Iran Khodro's suppliers and their quantitative information relative to economic, environmental, and social criteria is presented in Table 15. Regarding environmental sub-criteria, the evaluation team at IKCO, consisting of experts in this field, has evaluated the suppliers at three levels: 1 (good), 2 (middle), and 3 (poor) at the environmental management system criterion and 1 (low), 2 (middle), and 3 (high), respectively, at resource consumption and environmental pollution criteria.

The supplier ratings are calculated on the basis of a pairwise comparison matrix and a computing eigen criteria based on various criteria and sub-criteria, according to the concrete data set out in Table 15. Table 16 shows the results of the computations. The weightings of criteria, sub-criteria and supplier ratings should be combined in order to calculate the final score for each provider. The product of the supplier ratings and global weights shall be calculated in this way. Table 16 shows the result of supplier weights. According to the final value of weights of 4 suppliers shown in Table 16, we find that supplier 2 (ISACO) has the greatest weight value, followed by supplier 3 (SAPCO), and supplier 4 (MCPCO) and supplier 1 (IRANCO) possess similar weight values. The calculations performed in this section follow the SAW method.

Table 16 shows the final weights of suppliers using the SAW method. Additionally, the final weights of suppliers using the TOPSIS method have also been calculated, and the results are presented in Table 17. It is important to mention this point that the results of ranking Iran Khodro's suppliers using both methods are identical (both methods show that, in the ranking of Iran Khodro's suppliers based on sustainability indices, ISACO is in the first place).

Tab. 7. Value setting for different sub-criteria.

Value	Price	Technical level	Defects	Supply capacity	On-time delivery	Warranty period	Repair turn round time	Employee satisfaction	Resource consumption	Environment management system	Environment pollution	Decision
1	Low	High	Low	Great	Good	Long	Short	High	Low	Good	Low	Good
2	Middle	Middle	Middle	Middle	Middle	Not too long	Not too long	Middle	Middle	Middle	Middle	Middle
3	High	Low	High	Small	Poor	Short	Long	Low	High	Poor	High	Poor

Tab. 8. Economic sub-criteria decision table.

U	Price	Defects	Supply capacity	Technical level	Decision
1	1	1	2	2	Good
2	1	2	2	1	Good
3	1	2	3	3	Middle
4	2	2	2	2	Middle
5	2	1	1	3	Middle
6	3	2	1	1	Poor
7	3	1	2	2	Middle
8	1	3	2	3	Middle
9	3	2	2	1	Poor
10	3	1	1	1	Middle
11	2	2	1	1	Middle
12	2	3	2	2	Poor
13	2	2	2	3	Middle
14	2	2	3	2	Poor
15	1	1	3	3	Middle
16	2	3	1	3	Poor
17	1	1	1	3	Good
18	1	1	3	1	Good

Tab. 9. Environmental sub-criteria decision table.

U	Environment pollution	Resource consumption	Environment management system	Decision
1	1	1	2	Good
2	1	2	1	Good
3	1	2	2	Middle
4	2	1	2	Good
5	2	2	1	Middle
6	2	2	2	Middle
7	1	1	3	Middle
8	3	1	2	Middle
9	3	3	2	Poor
10	2	3	2	Poor

Tab. 10. Social sub-criteria decision table.

U	On-time delivery	Repair turn round time	Warranty period	Employee satisfaction	Decision
1	1	1	2	2	Good
2	1	2	2	1	Good
3	1	2	3	3	Middle
4	2	2	2	2	Middle
5	2	1	1	3	Middle
6	3	2	1	1	Poor
7	3	1	2	2	Middle
8	1	3	2	3	Middle
9	3	2	2	1	Poor
10	3	1	1	1	Middle
11	2	2	1	1	Middle
12	2	3	2	2	Poor
13	2	2	2	3	Middle
14	2	2	3	2	Poor
15	1	1	3	3	Middle
16	2	3	1	3	Poor
17	1	1	1	3	Good
18	1	1	3	1	Good

Tab. 11. Economic sub-criteria computational results.

	SGF	Weights	ε^*
Price	0.1337	0.4000	
Defects	0.1003	0.3000	0
Supply capacity	0.0669	0.2000	
Technical level	0.0334	0.1000	

Tab. 12. Environmental sub-criteria computational results.

	SGF	Weights	ε^*
Environment pollution	0.1431	0.2715	
Resource consumption	0.2635	0.5000	0
Environment management system	0.1204	0.2285	

Tab. 13. Social sub-criteria computational results.

	SGF	Weights	ε^*
On-time delivery	0.1337	0.4000	
Repair turn round time	0.1003	0.3000	0
Warranty period	0.0669	0.2000	
Employee satisfaction	0.0334	0.1000	

Tab. 14. Priority orders of criteria and sub-criteria.

Criteria	Local weights	Sub-criteria	Local weights	Global weights	Priority order
Economic	0.4321	Price	0.4000	0.17284	1
		Defects	0.3000	0.12963	3
		Supply capacity	0.2000	0.08642	6
		Technical level	0.1000	0.04321	10
Environmental	0.3333	Environment pollution	0.2715	0.09049	5
		Resource consumption	0.5000	0.16665	2
		Environment management system	0.2285	0.07616	7
Social	0.2346	On-time delivery	0.4000	0.09384	4
		Repair turn round time	0.3000	0.07038	8
		Warranty period	0.2000	0.04692	9
		Employee satisfaction	0.1000	0.02346	11

Tab. 15. Supplier's quantitative information.

Employee satisfaction (%)	Warranty period (month)	Repair turn round time (week)	On-time delivery (rate)	Environment management system (grade)	Resource consumption (grade)	Environment pollution (grade)	Technical level (grade)	Supply capacity (part)	Defects (rate)	Price ($)	Suppliers
0.75	4	2	0.85	1	2	3	3	400	0.04	55	Supplier 1 IRANCO
0.8	3	1	0.95	2	1	2	2	700	0.01	40	Supplier 2 ISACO
0.83	3	1	0.98	2	2	1	1	600	0.02	45	Supplier 3 SAPCO
0.85	4	3	0.9	2	3	1	1	500	0.06	50	Supplier 4 MCPCO

Tab. 16. Supplier's final weights using SAW method.

Supplier weights	Employee satisfaction (%)	Warranty period (month)	Repair turn round time (week)	On-time delivery (rate)	Environment management system (grade)	Resource consumption (grade)	Environment pollution (grade)	Technical level (grade)	Supply capacity (part)	Defects (rate)	Price ($)	Suppliers
0.2043	0.75	4	2	0.85	1	2	3	3	400	0.04	55	Supplier 1 IRANCO
0.3209	0.8	3	1	0.95	2	1	2	2	700	0.01	40	Supplier 2 ISACO
0.2664	0.83	3	1	0.98	2	2	1	1	600	0.02	45	Supplier 3 SAPCO
0.2084	0.85	4	3	0.9	2	3	1	1	500	0.06	50	Supplier 4 MCPCO

Tab. 17. Supplier's final weight using TOPSIS method.

Supplier weights	Employee satisfaction (%)	Warranty period (month)	Repair turn round time (week)	On-time delivery (rate)	Environment management system (grade)	Resource consumption (grade)	Environment pollution (grade)	Technical level (grade)	Supply capacity (part)	Defects (rate)	Price ($)	Suppliers
0.2016	0.75	4	2	0.85	1	2	3	3	400	0.04	55	Supplier 1 IRANCO
0.3222	0.8	3	1	0.95	2	1	2	2	700	0.01	40	Supplier 2 ISACO
0.2734	0.83	3	1	0.98	2	2	1	1	600	0.02	45	Supplier 3 SAPCO
0.2028	0.85	4	3	0.9	2	3	1	1	500	0.06	50	Supplier 4 MCPCO

4. Model descriptions

Specifying the buying criteria and assessing the supplier's performance are crucial before making a supplier selection. The model used to purchase criteria such as price, disadvantages, and on time delivery in current paper. The selection of those criteria is based on the fact that they were already identified as three most important factors for selecting a supplier. It is assumed that there are I products $i = 1, 2, \dots, I$ are to be bought from J suppliers $j = 1, 2, \dots, J$, and each of these suppliers offers different levels of price, product quality, on-time delivery performance, and supply capacity for the products they sell. Based on the total purchase value, supplier j offers relative price discounts based on the transaction volume (supplier j has discount intervals $r = 1, 2, \dots, m_j$). The notations used to formulate the investigated problem are as follows:

S_i: List of suppliers that offer a product i.

K_j: List of products that offered via supplier j.

W_j: Set of final weight value of supplier j.

R_j: List of discount interval of supplier j.

m_j : Discount intervals number in schedule of discount of supplier j.

r: Interval of discount, $1 \leq r \leq m_j$.

b_{jr}: Upper constraint in interval r of supplier j's (plan of discount), $0 = b_{j0} < b_{j1} < \dots < b_{j,m_j}$.

d_{jr} : The coefficient of discount related with interval r of supplier j's discount schedule.

P_{ij}: The price of unit of product i stipulated via

supplier j.
q_{ij}: The rate of defective of product i suggested via supplier j.
Q_i: The maximum acceptable defect rate of the item i which is determined by the buyer.
t_{ij}: The rate of on-time delivery of product i suggested via supplier j.
T_i: The minimum acceptable on-time delivery rate of the item i which is determined by the buyer.
C_{ij}: The maximum capacity of supply of product i suggested via supplier j.
D_i: The sum of demand of product i.
X_{ij}: Units of item i to purchase from supplier j.
V_{jr}: Volume of business purchased from supplier j in discount interval r.
y_{jr} : The binary integer variables, $y_{jr} = 1$ if volume of business purchased from supplier j falls on the discount interval r of its discount schedule; $y_{jr} = 0$, otherwise.

4.1. Objective functions

A multi-objective optimization model has been developed in current paper with a view to helping the decision maker select sustainable suppliers. For the selection of suppliers, the model uses three criteria: price, defect rate, and delivery time. The 4 objective functions of this model presented in current article are written like this:

1. Since W_j is the sustainability weight of supplier j and X_{ij} is the number of units purchased of item i from supplier j, therefore more purchases should be made from suppliers with higher sustainability weights. Therefore, the amount should be maximized. This objective function is formulated as Eq. (28):

$$Max\ Z_1 = \sum_{i\in K_j} \sum_{j\in S_i} W_j X_{ij} \tag{28}$$

2. Taking into account cumulative price discounts from the supplier, the buyer aims to minimizing the sum of purchase cost. This objective function is expressed by Eq. (29):

$$Min\ Z_2 = \sum_{j\in S_i} \sum_{r\in R_j} (1 - d_{jr}) V_{jr} \tag{29}$$

3. The buyer anticipates receiving a minimal quantity of defective products (items) from the supplier. In this case, objective function is expressed by Eq. (30):

$$Min\ Z_3 = \sum_{i\in K_j} \sum_{j\in S_i} q_{ij} X_{ij} \tag{30}$$

4. The fourth objective function (Eq. (31)) represents the buyer's desire to receive the maximum number of items delivered on time by the supplier.

$$Max\ Z_4 = \sum_{i\in K_j} \sum_{j\in S_i} t_{ij} X_{ij} \tag{31}$$

4.2. Constraints

Capacity limitations of the supplier, price discounts, demand from customers, quality and on-time delivery requests expressed as follows are important constraints to this problem:

- *Limitation of capacity*. As supplier j can provide up to C_{ij} units of item i and its order quantity X_{ij} should be equal or less than its capacity, these limitations are as Eq. (32):

$$X_{ij} \le C_{ij}\ ;\ i \in K_j,\ \ j \in S_i \tag{32}$$

- *Limitation of discount*. Volume of business V_{jr} from supplier j should be in appropriate discount interval r of discount pricing schedule and only in one interval. It can be stated as Eq. (33):

$$\begin{aligned} & b_{j,r-1} y_{jr} \le V_{jr} \le b_{jr} y_{jr}\ ;\ \ j \in S_i,\ \ r \in R_j \\ & \sum_{r\in R_j} y_{rj} \le 1 \qquad ;\ j \in S_i \end{aligned} \tag{33}$$

- *Limitation of demand*. The amount ordered from suppliers should be enough to meet the buyer's needs, according to Eq. (34):

$$\sum_{j\in S_i} X_{ij} = D_i\ ;\ \ i \in K_j \tag{34}$$

- *Limitation of quality*. Since Q_i is the buyer's maximum acceptable defective rate of item i and q_{ij} is the defective rate of supplier j, the quality limitation can be shown as Eq. (35):

$$\sum_{i\in K_j} \sum_{j\in S_i} q_{ij} X_{ij} \le Q_i D_i \tag{35}$$

- *Limitation of delivery*. Since T_i is the buyer's minimum acceptable on-time delivery rate of item i and t_{ij} is the on-time delivery rate of supplier j, the delivery limitation can be shown as Eq. (36):

$$\sum_{i\in K_j}\sum_{j\in S_i}(1-t_{ij})X_{ij} \le (1-T_i)\,D_i \qquad (36)$$

4.3. Final multi-objective model

The following will be shown as Eq. (37) the final integrated MOMIP model:

$$Max\ Z_1 = \sum_{i\in K_j}\sum_{j\in S_i} W_j X_{ij}$$
$$Min\ Z_2 = \sum_{j\in S_i}\sum_{r\in R_j}(1-d_{jr})V_{jr}$$
$$Min\ Z_3 = \sum_{i\in K_j}\sum_{j\in S_i} q_{ij}X_{ij}$$
$$Max\ Z_4 = \sum_{i\in K_j}\sum_{j\in S_i} t_{ij}X_{ij}$$
$$Subject\ to:$$
$$\sum_{r\in R_j} V_{jr} = \sum_{i\in K_j} P_{ij}X_{ij},\ \ j\in S_i$$
$$\sum_{j\in S_i} X_{ij} = D_i;\ \ i\in K_j$$
$$\sum_{i\in K_j}\sum_{j\in S_i} q_{ij}X_{ij} \le Q_i D_i$$
$$\sum_{i\in K_j}\sum_{j\in S_i}(1-t_{ij})X_{ij} \le (1-T_i)\,D_i$$
$$X_{ij} \le C_{ij};\ \ i\in K_j,\ \ j\in S_i$$
$$b_{j,r-1}y_{jr} \le V_{jr} \le b_{jr}y_{jr};\ \ j\in S_i,\ \ r\in R_j$$
$$\sum_{r\in R_j} y_{rj} \le 1 \qquad ;\ j\in S_i$$
$$X_{ij} \ge 0;\ \ i\in K_j,\ \ j\in S_i \qquad (37)$$

5. Case Study: Iran Khodro

A case study is developed and performed using concrete data from the IKCO with a view to validating the model at hand. Suppose that four suppliers (IRANCO, ISACO, SAPCO, and MCPCO) are incorporated in the assessment process and their price, defects, delivery and capacity are provided the same as in Table 15. In order to buy a single product from the best suppliers, IKCO would like to use an optimum number of orders for each supplier. Where the demand is more than 1200 units, the tolerable defective rate shall be 0.02 and the minimum satisfactory on-time delivery should be 0.92. As indicated in Table 18, four suppliers have a similar volume discount schedule with three rebate periods.

Tab. 18. The plan of volume discount.

r	Volume of business (in 1000$)	%Discount
1	0 to under 10	0
2	10 to under 20	5
3	20 and over	10

The following multi-objective programming model (Eq. (38)) should be developed in order to identify optimal quantities of orders for suppliers:

$$Max\,Z_1 = 0.2016X_1 + 0.3222X_2 + 0.2734X_3 + 0.2028X_4$$
$$Min\,Z_2 = \sum_{j=1}^{4}\sum_{r=1}^{3}(1-d_{jr})V_{jr}$$
$$Min\,Z_3 = 0.04X_1 + 0.01X_2 + 0.02X_3 + 0.06X_4$$
$$Max\,Z_4 = 0.85X_1 + 0.95X_2 + 0.98X_3 + 0.90X_4$$

$$Subject\ to:$$

$$V_{jr} = P_j X_j\ ;\ \ j = 1,2,3,4\ \ ,\ \ r = 1,2,3$$
$$X_1 + X_2 + X_3 + X_4 = 1200$$
$$0.04X_1 + 0.01X_2 + 0.02X_3 + 0.06X_4 \le 1200 \times 0.02$$
$$0.15X_1 + 0.05X_2 + 0.02X_3 + 0.10X_4 \le 1200 \times (1-0.92)$$
$$X_1 \le 400\ \ ,\ \ X_2 \le 700\ \ ,\ \ X_3 \le 600\ \ ,\ \ X_4 \le 500$$
$$b_{j,r-1}y_{jr} \le V_{jr} \le b_{jr}y_{jr}\ ;\ \ j = 1,2,3,4\ \ ,\ \ r = 1,2,3$$
$$\sum_{r=1}^{3} y_{jr} \le 1\ \ ;\ \ j = 1,2,3,4$$
$$X_j \ge 0\quad ;\ \ j = 1,2,3,4 \tag{38}$$

Use the optimization tool box in MATLAB (Release 13) to solve this problem. [65]. The 18 feasible solutions and the best possible solution are shown in Table 19 after MATLAB's process has been solved.

Tab. 19. Optimal solution of developed model.

	X_1	X_2	X_3	X_4	Z_1	Z_2	Z_3	Z_4
Optimal solution	0	700	50	0	362	4545	17	1155

6. Conclusion

Decisions on the appropriate selection of sustainable suppliers and on the allocation of order quantities to sustainable suppliers, in the case of multiple sourcing with multiple criteria and with capacity constraints of suppliers, are not given much attention in the literature. The increased attention to supplier partnerships does not only increase the importance of sustainability in selecting suppliers, but also has an impact on taking into account quality considerations during this selection process. In order to reach a consensus decision, BWM may be very useful in reaching out to several stakeholders who have divergent interests. By improving the BWM with the rough set theory in this paper, it is possible to quantify the qualitative judgement in order to make the comparison more intuitional and reduce or eliminate the assessment bias in the pairwise comparison process. In the supply chain of Iran Khodro Company, a proposed model for determining sustainability weights has been applied. The results obtained indicate that the inconsistency level in the BWM method, using the proposed approach, becomes zero at all stages. This clearly shows that the use of the proposed approach in this study enhances the consistency level in the BWM method and provides more consistent results. Furthermore, the TOPSIS and SAW methods were used to determine the weights of Iran Khodro Company's suppliers, and the results of both methods were compared. As observed, the results of ranking Iran Khodro Company's suppliers based on sustainability criteria are identical using both methods. According to the results of this study, ISACO holds the top position in the ranking of Iran Khodro Company's suppliers based on sustainability criteria. By comparing the results of this paper with the research of Amiri et al. [61] who used the fuzzy BWM for SSS problem in Iran Khodro Company, it can be seen that the results of ranking the supplier are the same in both methods. The results of both studies showed that the best sustainable supplier was a 2nd supplier, ISASCO Parts Supply Company. SSS is complicated by taking into account the capacity constraints of the suppliers and the price discounts. This paper presents a multi-objective matrixed integer programming model to encourage sustainable selection of suppliers that take into account both quantitative and qualitative factors. The BWM model offers a viable option in terms of sustainable selection of suppliers through price discounts, thanks to the existence of MATLAB software libraries that provide flexible and efficient calculational tools to solve models. Results of a case study in IKCO are presented in Table 19 and show that the most orders are assigned to the second supplier (ISACO Parts Supply Company). The paper suggests that the model could help buyers to select an optimal set of sustainable suppliers for their use and allocate order volumes among them. The application of the provided model indicates that, when selecting sustainable suppliers, it may be used to improve group decisions. Furthermore, it has been discovered that the decision-making procedure is thorough and that supplier selection with price reductions is easily accessible to the purchaser.

References

[1] Ghadimi, P., Toosi, F. G., & Heavey, C. A multi-agent systems approach for sustainable supplier selection and order allocation in a partnership supply chain. *European Journal of Operational Research*, Vol. 269, No. 1, (2017), pp. 286-301.

[2] Cheraghalipour, A., & Farsad, S. A bi-objective sustainable supplier selection and order allocation considering quantity discounts under disruption risks: A case study in plastic industry. *Computers & Industrial Engineering,* Vol. 118, (2018), pp. 237-250.

[3] Govindan, K., Khodaverdi, R., & Jafarian, A. A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. *Journal of Cleaner production,* Vol. 47, (2013), pp. 345-354.

[4] Liu, K., Liu, Y., & Qin, J. An integrated ANP-VIKOR methodology for sustainable supplier selection with interval type-2 fuzzy sets. *Granular Computing,* Vol. 3, No. 3, (2018), pp. 193-208.

[5] Rezaei, J. Best-worst multi-criteria decision-making method. *Omega,* Vol. 53, (2015), pp. 49-57.

[6] Alidaee, B., & Kochenberger, G. A. A note on a simple dynamic programming approach to the single-sink, fixed-charge transportation problem. Transportation Science, Vol. 39, No. 1, (2005), pp. 140-143.

[7] Li, S., Murat, A., & Huang, W. Selection of contract suppliers under price and demand uncertainty in a dynamic market. European Journal of Operational Research, Vol. 198, No. 3, (2009), pp. 830-847.

[8] Ho, W., Xu, X., & Dey, P. K. Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. European Journal of operational research, Vol. 202, No. 1, (2010), pp. 16-24.

[9] Mafakheri, F., Breton, M., & Ghoniem, A. Supplier selection-order allocation: A two-stage multiple criteria dynamic programming approach. International Journal of Production Economics, Vol. 132, No. 1, (2011), pp. 52-57.

[10] Chai, J., Liu, J. N., & Ngai, E. W. Application of decision-making techniques in supplier selection: A systematic review of literature. Expert systems with applications, Vol. 40, No. 10, (2013), pp. 3872-3885.

[11] Degraeve, Z., & Roodhooft, F. Effectively selecting suppliers using total cost of ownership. Journal of Supply Chain Management, Vol. 35, No. 4, (1999), pp. 5-10.

[12] Dickson, G. W. An analysis of vendor selection systems and decisions. Journal of purchasing, Vol. 2, No. 1, (1966), pp. 5-17.

[13] Weber, C. A., Current, J. R., & Benton, W.

C. Vendor selection criteria and methods. European journal of operational research, Vol. 50, No. 1, (1991), pp. 2-18.

[14] Razmi, J., & Rafiei, H. An integrated analytic network process with mixed-integer non-linear programming to supplier selection and order allocation. The International Journal of Advanced Manufacturing Technology, Vol. 49, (2010), pp. 1195-1208.

[15] Mendoza, A., & Ventura, J. A. An effective method to supplier selection and order quantity allocation. International journal of business and systems research, Vol. 2, No. 1, (2008), pp. 1-15.

[16] Ghorbani, M., Bahrami, M., & Arabzad, S. M. An integrated model for supplier selection and order allocation; using Shannon entropy, SWOT and linear programming. Procedia-Social and Behavioral Sciences, Vol. 41, (2012), pp. 521-527.

[17] Kannan, D., Khodaverdi, R., Olfat, L., Jafarian, A., & Diabat, A. Integrated fuzzy multi criteria decision making method and multi-objective programming approach for supplier selection and order allocation in a green supply chain. Journal of Cleaner production, Vol. 47, (2013), pp. 355-367.

[18] Nazari-Shirkouhi, S., Shakouri, H., Javadi, B., & Keramati, A. Supplier selection and order allocation problem using a two-phase fuzzy multi-objective linear programming. Applied Mathematical Modelling, Vol. 37, No. 22, (2013), pp. 9308-9323.

[19] Ware, N. R., Singh, S. P., & Banwet, D. K. A mixed-integer non-linear program to model dynamic supplier selection problem. Expert Systems with Applications, Vol. 41, No. 2, (2014), pp. 671-678.

[20] Singh, A. Supplier evaluation and demand allocation among suppliers in a supply chain. Journal of Purchasing and Supply Management, Vol. 20, No. 3, (2014), pp. 167-176.

[21] Scott, J., Ho, W., Dey, P. K., & Talluri, S. A decision support system for supplier selection and order allocation in stochastic, multi-stakeholder and multi-criteria environments. International Journal of Production Economics, Vol. 166, (2015), pp. 226-237.

[22] Lee, J., Cho, H., & Kim, Y. S. Assessing business impacts of agility criterion and order allocation strategy in multi-criteria supplier selection. Expert Systems with Applications, Vol. 42, No. 3, (2015), pp. 1136-1148.

[23] Jadidi, O., Cavalieri, S., & Zolfaghari, S. An improved multi-choice goal programming approach for supplier selection problems. Applied mathematical modelling, Vol. 39, No. 14, (2015). pp. 4213-4222.

[24] Guo, C., & Li, X. A multi-echelon inventory system with supplier selection and order allocation under stochastic demand. International Journal of Production Economics, Vol. 151, (2015), pp. 37-47.

[25] Kuo, T. C., Hsu, C. W., & Li, J. Y. Developing a green supplier selection model by using the DANP with VIKOR. Sustainability, Vol. 7, No. 2, (2015), pp. 1661-1689.

[26] Moghaddam, K. S. Fuzzy multi-objective model for supplier selection and order allocation in reverse logistics systems under supply and demand uncertainty. Expert Systems with Applications, 42(15-16), (2015), pp. 6237-6254.

[27] Sarrafha, K., Kazemi, A., & Alinezhad, A. A multi-objective evolutionary approach for integrated production-distribution planning problem in a supply chain network. Journal of Optimization in Industrial Engineering, Vol. 7, No. 14, (2014), pp. 89-102

[28] Govindan, K., Rajendran, S., Sarkis, J., & Murugesan, P. Multi criteria decision making approaches for green supplier

evaluation and selection: a literature review. Journal of cleaner production, Vol. 98, (2015), pp. 66-83.

[29] Amorim, P., Curcio, E., Almada-Lobo, B., Barbosa-Póvoa, A. P., & Grossmann, I. E. Supplier selection in the processed food industry under uncertainty. European Journal of Operational Research, Vol. 252, No. 3, (2016), pp. 801-814.

[30] Sodenkamp, M. A., Tavana, M., & Di Caprio, D. Modeling synergies in multi-criteria supplier selection and order allocation: An application to commodity trading. European Journal of Operational Research, Vol. 254, No. 3, (2016), pp. 859-874.

[31] PrasannaVenkatesan, S., & Goh, M. Multi-objective supplier selection and order allocation under disruption risk. Transportation Research Part E: Logistics and Transportation Review, Vol. 95, (2016). pp. 124-142.

[32] Hamdan, S., & Cheaitou, A. Supplier selection and order allocation with green criteria: An MCDM and multi-objective optimization approach. Computers & Operations Research, Vol. 81, (2016), pp. 282-304.

[33] Çebi, F., & Otay, I. A two-stage fuzzy approach for supplier evaluation and order allocation problem with quantity discounts and lead time. Information sciences, Vol. 339, (2016), pp. 143-157.

[34] Keshavarz Ghorabaee, M. K., Amiri, M., Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. A new multi-criteria model based on interval type-2 fuzzy sets and EDAS method for supplier evaluation and order allocation with environmental considerations. Computers & Industrial Engineering, Vol. 112, (2017), pp. 156-174.

[35] Noori-Daryan, M., Taleizadeh, A. A., & Jolai, F. Analyzing pricing, promised delivery lead time, supplier-selection, and ordering decisions of a multi-national supply chain under uncertain environment. International journal of production economics, Vol. 209, (2019), pp. 236-248.

[36] Hamdan, S., & Cheaitou, A. Dynamic green supplier selection and order allocation with quantity discounts and varying supplier availability. Computers & Industrial Engineering, Vol. 110, (2017), pp. 573-589.

[37] Hamdan, S., & Cheaitou, A. Datasets for supplier selection and order allocation with green criteria, all-unit quantity discounts and varying number of suppliers. Data in brief, Vol. 13, (2017), pp. 444-452.

[38] Vahidi, F., Torabi, S. A., & Ramezankhani, M. J. Sustainable supplier selection and order allocation under operational and disruption risks. Journal of Cleaner Production, Vol. 174, (2018), pp. 1351-1365.

[39] Esmaeili-Najafabadi, E., Nezhad, M. S. F., Pourmohammadi, H., Honarvar, M., & Vahdatzad, M. A. A joint supplier selection and order allocation model with disruption risks in centralized supply chain. Computers & Industrial Engineering, Vol. 127, (2019), pp. 734-748.

[40] Park, K., Kremer, G. E. O., & Ma, J. A regional information-based multi-attribute and multi-objective decision-making approach for sustainable supplier selection and order allocation. Journal of cleaner production, Vol. 187, (2018), pp. 590-604.

[41] Lo, H. W., Liou, J. J., Wang, H. S., & Tsai, Y. S. An integrated model for solving problems in green supplier selection and order allocation. Journal of cleaner production, Vol. 190, (2018), pp. 339-352.

[42] Hosseini, S., Morshedlou, N., Ivanov, D., Sarder, M. D., Barker, K., & Al Khaled, A. Resilient supplier selection and optimal order allocation under disruption risks. International Journal of Production Economics, Vol. 213, (2019), pp. 124-

137.

[43] Kellner, F., & Utz, S. Sustainability in supplier selection and order allocation: Combining integer variables with Markowitz portfolio theory. Journal of cleaner production, Vol. 214, (2019), pp. 462-474.

[44] Wong, J. T. Dynamic procurement risk management with supplier portfolio selection and order allocation under green market segmentation. Journal of Cleaner Production, Vol. 253, (2020), p. 119835.

[45] Jia, R., Liu, Y., & Bai, X. Sustainable supplier selection and order allocation: Distributionally robust goal programming model and tractable approximation. Computers & Industrial Engineering, Vol. 140, (2020), p. 106267.

[46] Khoshfetrat, S., Rahiminezhad Galankashi, M., & Almasi, M. Sustainable supplier selection and order allocation: a fuzzy approach. Engineering Optimization, Vol. 52, No. 9, (2020), pp. 1494-1507.

[47] Nasr, A. K., Tavana, M., Alavi, B., & Mina, H. A novel fuzzy multi-objective circular supplier selection and order allocation model for sustainable closed-loop supply chains. Journal of Cleaner production, Vol. 287, (2020), p. 124994.

[48] Li, F., Wu, C. H., Zhou, L., Xu, G., Liu, Y., & Tsai, S. B. A model integrating environmental concerns and supply risks for dynamic sustainable supplier selection and order allocation. Soft Computing, Vol. 25, (2021), pp. 535-549.

[49] Alinezhad, A., & Khalili, J. EDAS method. New methods and applications in multiple attribute decision making (MADM), (2019), pp. 153-159.

[50] Cui, L., Wu, H., & Dai, J. Modelling flexible decisions about sustainable supplier selection in multitier sustainable supply chain management. International Journal of Production Research, Vol. 61, No. 14, (2021), pp. 4603-4624.

[51] Sontake, A., Jain, N., & Singh, A. R. Sustainable supplier selection and order allocation considering discount schemes and disruptions in supply chain. In Operations Management and Systems Engineering: Select Proceedings of CPIE (2021), pp. 61-94. Springer Singapore.

[52] Beiki, H., Mohammad Seyedhosseini, S., V. Ponkratov, V., Olegovna Zekiy, A., & Ivanov, S. A. Addressing a sustainable supplier selection and order allocation problem by an integrated approach: a case of automobile manufacturing. Journal of Industrial and Production Engineering, Vol. 38, No. 4, (2021), pp. 239-253.

[53] Aditi, Kannan, D., Darbari, J. D., & Jha, P. C. Sustainable supplier selection model with a trade-off between supplier development and supplier switching. Annals of Operations Research, Vol. 331, No. 1, (2022), pp. 351-392.

[54] Sharma, R., & Darbari, J. D. (2021). Integrated optimization model for sustainable supplier selection and order allocation in food supply chain. In Soft Computing for Problem Solving: Proceedings of SocProS 2020, Vol. 2 pp. 557-572. Springer Singapore.

[55] Gidiagba, J., Tartibu, L., & Okwu, M. Sustainable supplier selection in the oil and gas industry: An integrated multi-criteria decision making approach. Procedia Computer Science, Vol. 217, (2023), pp. 1243-1255.

[56] Azizi nafteh, M., & Shahrokhi, M. (2023). Presenting a Mathematical Programming Model for Sustainable Supplier Selection and Order Allocation Using the COPRAS Method. Supply Chain Management, Vol. 25, No. 79, pp. 87-101.

[57] Ratna, S., Bhat, M., Singh, N. P., Saxena, M., Misra, S., Vishwakarma, P. N., & Kumar, B. Sustainable Supplier Selection in Automobile Sector Using GRA–TOP Model. In Advances in Industrial and Production Engineering: Select Proceedings of FLAME, (2023), pp. 393-400. Springer Singapore.

[58] Zhang, J., Li, L., Zhang, J., Chen, L., & Chen, G. Private-label sustainable supplier selection using a fuzzy entropy-VIKOR-based approach. Complex & Intelligent Systems, Vol. 9, (2023), pp. 2361-2378.

[59] Xia, W., & Wu, Z. Supplier selection with multiple criteria in volume discount environments. Omega, Vol. 35, No. 5, (2007). pp. 494-504.

[60] Zhang, Z., Liao, H., Al-Barakati, A., Zavadskas, E. K., & Antuchevičienė, J. Supplier selection for housing development by an integrated method with interval rough boundaries. International Journal of Strategic Property Management, Vol. 24, No. 4, (2020), pp. 269-284.

[61] Amiri, M., Hashemi-Tabatabaei, M., Ghahremanloo, M., Keshavarz-Ghorabaee, M., Zavadskas, E. K., & Banaitis, A. A new fuzzy BWM approach for evaluating and selecting a sustainable supplier in supply chain management. International Journal of Sustainable Development & World Ecology, Vol. 28, No. 2, (2020), pp. 125-142.

[62] Alinezhad, A., & Khalili, J. MABAC method. New methods and applications in multiple attribute decision-making (MADM), (2019), pp. 199-204.

[63] Guoyin, W. Theory and Knowledge Acquisition of Rough Sets, Xi'an Jiao Tong University Publication, (In Chines), (2001).

[64] Matlab Version 6.5 Release 13. The MathWorks, Inc., 3 Apple Hill Dr., Natick, MA 01760-2098; 508/647-7000, Fax 508/647-7001, www.mathworks.com

Follow this article at the following site:

Amin Amini, Alireza Alinezhad & Davood Gharakhani. A Hybrid Method using MODM and BWM for Supplier Assessment under Uncertainty. IJIEPR 2024; 35 (2) :1-25
URL: http://ijiepr.iust.ac.ir/article-1-2004-en.html