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Presenting an integrated BWM-VIKOR-based approach for selecting suppliers of raw materials in the supply chain with emphasis on agility and flexibility criteria (Case study: Saipa corporation)

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Abstract. In this study, in order to select suppliers of raw materials for Saipa Automotive Corporation as one of the largest factories in Iran, environment, flexibility, and agility criteria are studied and, then, some sub-criteria are also considered for each criterion. The sub-criteria include green design, clean technology, environmental performance, agility in operational systems, market agility, logistics agility, product flexibility, flexibility in transportation, and resource flexibility. It should be mentioned that the assumed criteria are applied based on the characteristics of the case study. Therefore, the main variables required for the identification of criteria that affect the selection of suppliers are studied with regard to environmental factors within the case study. In order to rank suppliers and select the best ones, the best-worst multi-criteria decision-making method (BWM) and VIKOR approach are used. According to the calculations based on the proposed process in this study and the information about the desired criteria, 7 suppliers are selected as the best ones. Since the approach presented in this study has combined BWM to determine weights and VIKOR method for the final ranking of options, this approach can be also applied to other studies.

1. Introduction

In order to gain competitive advantages in the market, manufacturers must collaborate with not only component or raw material suppliers but also wholesalers/distributors, retailers, and customers, all of whom participate in a supply chain, directly or indirectly, in order to meet customer demands. Supply Chain Management (SCM) involves the management of transaction flows among players in a supply chain so as to maximize total supply chain profitability. SCM aims to minimize the overall costs across the supply chain and to maximize the revenue generated from the customer in cooperation with business partners. Firms within a supply chain can achieve sustainable competitive advantage by developing much closer relationships with all companies, and they can significantly reduce time and costs depending on the appropriate management of the supply chain while serving customer needs

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at the same time [1]. Once a supplier becomes part of a well-managed and established supply chain, it will have a lasting effect on the competitiveness of the entire supply chain. The importance of supplier selection comes from the fact that "it commits resources while simultaneously impacting such activities as inventory management, production planning and control, cash flow requirements, and product quality" [2]. Nowadays, specific attention to these responsibilities as a context for profitability and sustainable growth is followed within organizations [3,4]. In the relevant studies of supply chain, supplier selection in the traditional environment regardless of sustainability factors has been mostly considered [5]. A rapid increase in knowledge in today's industries is observed on the supply chain. Since many companies pollute the natural environment and the surroundings, it can, in turn, affect companies considerably so that they may consider environmental issues in their activities. Although the population is increasing and the available resources are decreasing, companies have found that their suppliers should be capable of redesigning. From the perspective of companies, they should imagine good environmental image of products, processes, systems, and technology [6].

Kahraman et al. [7] studied the fuzzy hierarchical process to select the best supplier so as to satisfy the determined criteria at a deeper level. Cakravastia & Takashi [8] developed an integrated supplier selection and negotiation process to provide raw materials and assembly parts. The main objective of this study was to integrate the decisions into domestic production supply chain based on demand. Hwang et al. [9] presented an analytical model of supplier selection with regard to Analytical Hierarchy Process (AHP) and integrated method of analysis of results. Chen et al. [10] presented a fuzzy decision-making approach to solve the supplier selection problem in the supply chain. Liao and Rittscher [11] conducted a study to analyze the supplier flexibility with regard to demand rate and time uncertainty. Kumar et al. [12] provided an integrated approach using analytic hierarchical process and fuzzy linear programming for supplier selection and the problem of share allocation. Kokangul and Susuz [13] conducted a study to present an integrated AHP approach and multi-objective integer nonlinear programming under limitations such as discount rate, capacity, and budget to determine the best suppliers, considering the optimal economic value among them. Kuo et al. [14] developed a model for green supplier selection through the integration of Artificial Neural Network (ANN) and Data Envelopment Analysis (DEA), multi-criteria decision-making, and network analysis process. The approach is introduced as an ANN-MAA method; therefore, in addition to traditional criteria of supplier selection, environmental regulations are considered. Finally, based on model analysis results, the proposed approach showed better performance in the field of green suppliers using two methods of ANN-DEA and AHP-DEA.

Yakovleva et al. [15] provided a methodology for measuring sustainability of the food supply chain along with 45 indices in 3 dimensions of economic, social, and environmental. The proposed framework was analyzed using statistical data for potato and UK chicken supply chain using AHP technique and the opinion of experts.

Shaw et al. [16] introduced an approach to select the supplier in the supply chain according to the problem of carbon emission using fuzzy multi-objective linear programing and AHP method. Govindan et al. [17] analyzed innovations of sustainable supply chain and identified the model impacts in terms of economic, environmental, and social aspects for supplier selection operation in supply chain through the presentation of a fuzzy multi-criteria approach. Junior et al. [18] conducted a study to conduct sensitivity analysis of Fuzzy AHP (FAHP) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) methods in the field of supplier selection decision-making. Hashemi et al. [19] studied economic and environmental criteria to present a comprehensive model for green supplier selection.

Kumar et al. [20] presented a unique study to demonstrate how different demands of suppliers can be optimized with regard to criteria of economic, social, and environmental sustainability. Bakeshlou et al. [21] developed a fuzzy linear multi-objective programming model for the supplier selection problem with regard to 17 criteria in 5 clusters so that a fuzzy multi-objective decision approach was used to solve it. The main objective of this study is to select the best suppliers with regard to optimal allocation of demand in a condition where demand and capacity of a supplier are restricted. In the proposed combined algorithm, a fuzzy decision method and an analytical method are used to understand the relations between criteria, and Fuzzy ANP (FANP) method is also used to weight the criteria based on their dependence. In addition, a combined method based on FANP and Fuzzy Multi-Objective Linear Programming (FMOLP) was used to allocate optimal order to selected suppliers. Liu et al. [22] proposed a new evidential Analytic Network Process (ANP) methodology based on game theory to efficiently address supplier management under uncertain environment. They demonstrated that the proposed model enjoyed many advantages, efficiency, and rationality with regard to supplier selection problem. Banaeian et al. [23] compared the application of three popular multi-criteria supplier selection methods in a fuzzy environment. Their comparative analysis of the case study indicated that the fuzzy methods arrived at identical supplier rankings, yet fuzzy GRA required less computational complexity to generate

Table 1. A summary of relevant studies.

Authors	Ref.	Journal	Method
Kuo et al. (2010)	[14]	Journal of Cleaner Production	AHP-DEA
Yakovleva et al. (2011)	[15]	International Journal of Production Research	AHP
Shaw et al. (2012)	[16]	Expert Systems With Applications	FAHP - FMOLP
Govindan et al. (2013)	[17]	Journal of Cleaner Production	FTOPSIS
Junior et al. (2014)	[18]	Applied Soft Computing	FAHP - FTOPSIS
Hashemi et al. (2015)	[19]	International Journal of Production Economics	ANP-GRA
Karsak and Dursun (2015)	[27]	Computers & Industrial Engineering	QFD-Fuzzy AHP
Kumar et al. (2016)	[20]	International Journal of Computer Integrated Manufacturing	FAHP - FMOLP
Bakeshlou et al. (2017)	[21]	Journal of Intelligent Manufacturing	FANP - FMOLP
Yazdani et al. (2017)	[28]	Journal of Cleaner Production	QFD-AHP
Büyüközkan and Göçer (2017)	[29]	Applied Soft Computing	FAHP
Liu et al. (2018)	[22]	International Journal of Fuzzy Systems	DEMATEL
Banaeian et al. (2018)	[23]	Computers & Operations Research VIKOR-GRA	
Jain et al. (2018)	[24]	Neural Computing and Applications	AHP-TOPSIS
Chatterjee and Samarjit (2018)	[25]	Technological and Economic Development of Economy	Fuzzy-Rasch based COPRAS-G
Sahebjamnia (2018)	[26]	Scientia Iranica	FDEMATEL-ANP
Rabieh et al. (2018)	[40]	Scientia Iranica	FTOPSIS

the same results. Jain et al. [24] presented the selection of headlamp supplier using integrated fuzzy multi-criteria decision-making approaches, AHP, and TOPSIS. The results addressed that fuzzy approaches could be effective and more accurate than the existing approaches for supplier selection problems. Chatterjee and Samarjit [25] presented a wide-ranging decision-making technique for ranking supplier alternatives in view of the effect of selected criteria. The proposed method was developed and fuzzy-Rasch model was used by applying a five-point Likert scale to determine criteria weight and conduct grey-based complex proportional assessment (COPRAS-G) method for evaluating and ranking the potential alternatives as per criteria. The applicability of the induced methodology for the supplier selection problem in all environments was shown through a case study in telecommunication sector. Sahebjamnia [26] developed an integrated resilience model of supplier selection and order allocation. Fuzzy decision-making trial and evaluation laboratory (FDEMATEL) and ANP methods were applied to find the overall performance of each supplier. Rabieh et al. (2018) [40] presented an approach to select suppliers and determine their order allocation in a way that the performance of the sustainability of the supply process gets optimized on the whole by an integrated Delphi method, FTOPSIS, and multi-objective programming model.

Here, a summary of the above-mentioned studies is presented in Table 1.

According to a review of the literature, it was found that the majority of studies focused on ranking and evaluating suppliers regardless of environment, agility, and flexibility criteria. However, considering agility and flexibility has always been one of the most underlying criteria in making managerial decisions for the owners of supply chains. The criteria are important, since the owners of the chain tend to provide good environment in their servicing structure to make competitive advantages. The competitive advantage can attract customers and ultimately create loyal customers. Considering flexibility criterion and its sub-criteria can also make a good structure to cope with uncertainty conditions in predictions and sudden changes in the future. Therefore, considering agility and flexibility criteria can cause improvement in final decisions. Moreover, considering environmental factors can facilitate sustainability in final decisions, which

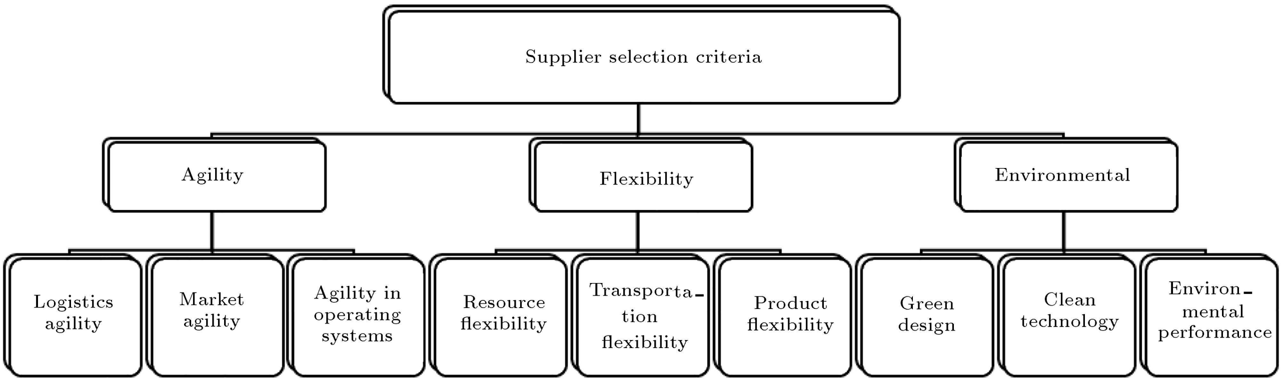

Figure 1. Criteria of the supplier selection process.

can be an effective step in the field of improvement in the existing structure. This issue is also important, since the growth of industries and production of environmental pollutants over the decade have resulted in the destruction of many natural resources, and some certain regulations have been codified in many countries to observe environmental criteria in different departments and, then, lack of observance of the regulations can impose lateral costs such as organizational fines. Therefore, in this study, in addition to considering BWM and VIKOR methods as new combined methods, the suppliers are ranked based on one aspect of sustainability including environmental factors.

2. Methodology

Today, using the application of environmental factors and criteria can be also highly effective in sustaining decisions to select suppliers. This study attempts to consider environmental criteria to select a good supplier, in addition to the criteria mentioned above. However, in the procedure of this study, according to the review of literature and careful analysis of the existing structure in domestic organizations, a change in the indices may be made. Therefore, this study is aimed at evaluating suppliers and selecting the best supplier based on identified criteria. In order to evaluate and select sustainable suppliers, qualitative and quantitative factors should be considered. Therefore, selecting a supplier is a type of the problem of multivariate decision-making criteria, and the method is suitable for solution. Today, considering environmental concept in relevant concepts of selecting suppliers is essential. The importance is intensified when the analysis of the relevant studies by environmental organizations shows the reality that even the smallest management and strategic decisions made by manufacturing organizations and firms can affect the emission of environmental pollutants. Therefore, considering the environmental criteria and factors is very important in selecting suppliers.

Hence, this study has attempted to review the relevant literature in the field of evaluation of suppliers and conduct an in-person interview with experts of the studied organization to analyze all effective criteria desired by the organization such as price, safety, credit and reputation, timely delivery, and so on or in the environmental aspect such as the degree of recyclability, the environmental impacts (pollution), the rate of implementation of environment-friendly technologies, the extent of the development of the product in line with the environment, and other green factors. It should be noted that the mentioned criteria may need revision during the study time depending on the opinion of experts. Therefore, the main variables in the problem of identifying criteria that affect supplier selection are taken with regard to environmental factors in this study. Selecting supplier evaluation criteria is one of the early steps of supplier selection process. Many studies have been conducted so far in the field of supplier selection and, accordingly, various criteria and methods are provided. In Table 2, some of the most underlying criteria that affect supplier evaluation are presented in brief.

According to the criteria used in different works, it can be found that environmental criteria have been almost considered in different articles. After quality, the two criteria of flexibility and agility are the next underlying factors.

Figure 1 shows the structure of the criteria of the supplier selection process.

3. Introduction of the proposed integrated approach

The approach proposed in this study combines BWM and VIKOR methods and ranks final options through weights allocated to each criterion and sub-criteria. In this approach, firstly, by using BWM, each criterion and sub-criterion was weighted and, then, by using Vikor method, final ranking was performed. The reason for choosing the BWM to weight criteria can be

Table 2. Criteria affecting supplier evaluation.

Authors	Ref.	Criteria for supplier selection
Ku et al. (2010)	[30]	Cost, quality, services, supplier profile, risk, buyer & seller participation, cultural and relationship barriers, business restraints, respect for policies, beneficiary rights, employee benefits and rights, environmental management system, ECO design requirements for energy consumables.
Ho et al. (2010)	[31]	Quality, affordability, prices and costs, ability to produce, services, management, technology, research and development, financial issues, flexibility, reputation and credit, lack of risk, security and environment.
Grisi et al. (2010)	[32]	Price, quality, delivery quality, environmental competency, green image, access to clean technologies, environmental management system, current environmental impact (air pollution).
Bai and Sarkis (2010)	[33]	Internal factors (security and discipline methods, employee contracts, job opportunities, R & D, health and safety, labor costs); external factors (security, service infrastructure, social harm, economic well-being and growth, consumer education, stakeholder empowerment, interaction with stakeholders).
Large and Thomsen (2011)	[34]	Strategic purchase level, Environmental commitment, Environmental purchasing capacity, Green supplier assessment, Purchasing performance, Environmental performance improvement, Green collaboration with supplier.
Mafakheri et al. (2011)	[35]	Cost, quality, environmental costs, delivery, green design, environmental management system, environmental competencies.
Amindoust et al. (2012)	[36]	Profit, quality, delivery, services, environmental management system, environmental competencies, worker safety and worker health, employee rights.
Shen et al. (2013)	[37]	Pollution made by production, consumption of resources, ECO design, green image, environmental management system, application of environmentally friendly technology, application of environment-friendly materials, environmental education.
Dargi et al. (2014)	[38]	Quality, price, geographical location, production capacity, service and delivery, credit, technical capacity and facilities.
Memon et al. (2015)	[39]	Quality, delivery, logistics services, sustainability factors (sustainability certificates, production methods, waste management, social rules), risk.

the presence of a mathematical model causing optimal allocation of weights. Since BWM does not use matrices such as the extended matrix in the VIKOR method and, also, the selections are made quite preferentially, VIKOR method is applied in this paper [41]. It can be considered as the final step of the proposed approach due to the developed decision matrix for the final determination of criteria. Synergy of the two methods can facilitate a good selection of final options. In the rest of the paper, the structure of the applied method is analyzed.

3.1. Best-worst method

BWM is the last multi-criteria decision-making technique presented by Rezaei (2015) [42], which is based on paired comparisons to obtain weights of options and relevant criteria. The method compensates the weaknesses of paired comparison-based approaches (e.g., AHP and ANP) such as inconsistency. The method decreases the number of paired comparisons considerably only through making reference comparisons. To this end, the experts and decision-makers are required only to determine the best criterion in comparison to other criteria and specify the priority of all criteria compared to the worst ones. In general, by eliminating secondary comparisons, this method can be faster and more efficient than existing methods for weighting the multi-criteria decision-making problems. The steps of this method are presented in the following:

Step 1: Determine the set of decision criteria. In this step, criteria $c_1, c_2, \dots, c_n$ used to achieve decision-making should be considered;

Step 2: Determine the best (e.g., most desirability and highest significance) and worst (e.g., lowest desirability, lowest importance) criteria (selection is optional if more than one criterion is considered as worst or best option). In this step, in general, the decision-maker identifies the best and worst criteria (sub-criterion). No comparison is made in this step;

Step 3: Determine the priority of the best criterion compared to others using numbers 1-9. The results of the vector are illustrated as follows:

$$A_B = (a_{B1}, a_{B2}, \dots a_{Bn}), \tag{1}$$

where a_{Bj} shows the priority of best criterion, B, compared to criterion j. Clearly, $a_{BB} = 1$;

Step 4: Determine the priority of all criteria compared to the worst criterion using numbers 1-9. The results of this vector are presented as follows:

$$A_W = (a_{1W}, a_{2W}, \dots, a_{nW})^T, \tag{2}$$

where a_{jW} shows the priority of criterion j compared to the worst criterion W. clearly, $a_{WW} = 1$;

Step 5: Determining optimal weights $(W_1^*, W_2^*, \dots, W_n^*)$ optimal weight for criterion is same weight for each pair W_B/W_j, W_j/W_W $\frac{W_B}{W_j} = a_{Bj}$, and $\frac{W_j}{W_W} = a_{jW}$. In order to provide these conditions for all js, maximum absolute value of differences of $|\frac{W_B}{W_j} - a_{Bj}|$ and $|\frac{W_j}{W_W} - a_{jW}|$ is minimized for all js. With regard to summation conditions and nonnegative weights, the model is:

$$\min \max_j \left\{ |\frac{W_j}{W_W} - a_{jW}|, |\frac{W_B}{W_j} - a_{Bj}| \right\},$$

s.t.

$$\sum_j W_j = 1,$$

$$W_j \geq 0, \text{ for all } j\text{s}. \tag{3}$$

Eq. (3) can be converted to:

$$\min \xi$$

s.t.

$$|\frac{W_B}{W_j} - a_{Bj}| \leq \xi \text{ for all } j\text{s},$$

$$|\frac{W_j}{W_W} - a_{jW}| \leq \xi \text{ for all } j\text{s},$$

$$\sum_j W_j = 1,$$

$$W_j \geq 0, \text{for all } j\text{s}. \tag{4}$$

Hence, through solving model (4), optimal weights $(W_1^*, W_2^*, \dots, W_n^*)$ and ξ^* are obtained as follows.

3.2. Consistency coefficient

In this section, consistency coefficient is presented for the BWM method.

Definition: A comparison is completely consistent, such that for all js, $a_{Bj} \times a_{jW} = a_{BW}$, where a_{Bj}, a_{jW}, and a_{BW} are, respectively, the best criteria compared to j, priority of j to the worst criterion, and priority of the best criterion to the worst one.

However, consistency may not be complete for some js. Hence, the consistency coefficient is proposed to show the consistency of comparative results. To this end, the least consistency is estimated comparatively as follows.

As mentioned before, the maximum possible value of $a_{ij} \in \{1, \ldots, a_{BW}\}$ is equal to 9 (or any other value identified by the decision-maker). The consistency decreases when $a_{Bj} \times a_{jW}$ is lower or higher than a_{BW} or $a_{Bj} \times a_{jW} \neq a_{BW}$; in addition, it is clear that most inconsistency occurs when a_{Bj} and a_{jW} are of the highest value (equal to a_{BW}), where it can result in ξ. Since $(\frac{W_B}{W_j}) \times (\frac{W_j}{W_W}) = W_B/W_W$ and maximum inconsistency is given as a result of the allocation of maximum value through a_{Bj} and a_{jW}, ξ is a value that should be subtracted from a_{Bj} and a_{jW} and be added to a_{BW}. In other words:

$$(a_{Bj} - \xi) \times (a_{jW} - \xi) = (a_{BW} + \xi). \quad (5)$$

For minimum consistency, let $a_{Bj} = a_{jW} = a_{BW}$; hence,

$$(a_{BW} + \xi) \times (a_{BW} + \xi) = (a_{BW} + \xi) \rightarrow \xi^2 - (1 + 2a_{BW})\xi + (a_{BW}^2 - a_{BW}) = 0. \quad (6)$$

By solving the above-presented equation per different values of $a_{BW} \in \{1, 2, ..., 9\}$, maximum value may be obtained as ξ. The value is reported as the consistency index in Table 3.

Therefore, the estimation of consistency index using ξ^* and corresponding CI is presented as follows:

$$\text{CR} = \frac{\xi^*}{\text{CI}}. \quad (7)$$

The closer the Cr is to (0.1), the higher the consistency of the already made comparisons will be.

3.3. Best-worst linear model

The space of solving problem (4) includes all positive values for W_j, $j = 1, \ldots, n$, where a summation of weights should be equal to 1, and the error of all weighted ratios derived from a peer-to-peer comparison is at maximum ξ. The proposed model by Rezaei [42] for decision-making problems with more than 3 criteria can lead to multiple optimal answers. Hence, to meet the problem due to nonlinearity of the model, Rezaei [41] presented the linear model (4), leading to a unique answer in a study as follows.

In this model, instead of minimizing the maximum value in set $\left\{|\frac{W_B}{W_j} - a_{Bj}|, \quad \frac{W_j}{W_W} - a_{jW}\right\}$, maximum value of set $\left\{\{|W_B - a_{Bj}W_j|, |W_j - a_{jW}W_W|\right\}$ is minimized. Therefore, the modes are formulated as follows:

$$\min \max_j \{|W_B - a_{Bj}W_j| \ , \ |W_j - a_{jW}W_W|\}$$

s.t.

$$\sum_j W_j = 1$$

$$W_j \geq 0, \text{ for all } j\text{s}. \quad (8)$$

Eq. (8) can be written as:

$$\min \xi^L$$

s.t.

$$|W_B - a_{Bj}W_j| \leq \xi^L \ , \text{ for all } j\text{s}$$

$$|W_j - a_{jW}W_W| \leq \xi^L \ , \text{ for all } j\text{s}$$

$$\sum_j W_j = 1$$

$$W_j \geq 0 \ , \text{ for all } j\text{s}. \quad (9)$$

The above-presented linear model has a unique answer. Hence, by solving model (9), optimized weights $(W_1^*, W_2^*, \ldots, W_n^*)$ and ξ^{L*} are obtained. For the above-presented model, ξ^{L*} shows direct consistency of the comparisons, and there is no need to use consistency index in Eq. (7). In general, ξ^{L*} values close to 0 show high consistency level [43].

3.4. VIKOR method

VIKOR method was proposed in 1998 by Opricovic [44] for the first time and was later proposed by Obricovic and Tzeng in 2002 [45] for complicated multi-criteria decision-making systems. The term VIKOR is the acronym of the Serbian phrase "VIseKriterijumskaOptimizacija I KompromisnoResenje", meaning compromise solution and multi-criteria optimization [46]. This method is aimed at emphasizing ranking and selection from a set of alternatives in a problem with conflicting criteria, which can be significantly helpful in achieving an optimal solution and selecting the best option. Here, compromise solution is a possible solution considering all ideas carefully, and compromise means the agreement created for common score allocation. Finally, the output of VIKOR method is a compromise ranking list along with one or more compromise solutions.

3.5. VIKOR method steps

The steps of decision-making problems using VIKOR method are as follows [46]:

Table 3. Consistency index.

a_{BW}	1	2	3	4	5	6	7	8	9
CI ($\max \xi$)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Step 1: Collect opinions of decision-makers to determine criteria and options to form a decision matrix.

Step 2: Calculate normalized values and formation of normalized matrix. It is assumed that there are m options and n criteria. Variable i is used to express options, and variable j is used to express criteria. Different i options are specified as x_i. For option i, criterion j is specified as x_{ij}; x_{ij} is the value of item i and criterion j.

For the normalization process, where x_{ij} is the main value of option i and criterion j, the following formula is used:

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}},$$

$$i = 1\ ,\ 2\ ,\ ...\ ,\ m; \qquad j = 1\ ,\ 2\ ,\ ...\ ,\ n. \tag{10}$$

Step 3: Determine the best and worst values. The best and worst values in each criterion are identified and named as f_j^* and f_j^-.

$$f_j^* = \max f_{ij} \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n, \tag{11}$$

$$f_i^- = \min f_{ij} \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n, \tag{12}$$

where f_j^* is the best positive ideal solution for criterion j, and f_j^- is the worst negative ideal solution for criterion j. If all f_j^-s are combined, an optimal combination can be created for providing the highest score, which also holds for f_j^-.

Step 4: Determine the weights of criteria. The weights of criteria should be calculated to express the importance of their relations. The weights can be obtained by different methods such as ANP, AHP, FANP, FAHP, Shannon entropy, and BWM (BWM method is used in this approach).

Step 5: Estimate the distance of options from the ideal solution. This step belongs to the estimation of distance of each option from the ideal solution and, then, their summation for the final value based on the following formula is as follows:

$$S_i = \sum_{j=1}^{n} W_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)}, \tag{13}$$

$$R_i = \max \left[W_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \right], \tag{14}$$

where S_i refers to the distance of option i from the positive ideal solution (best combination), and R_i refers to the distance of option i from the negative ideal solution (the worst combination). The best rank is obtained based on S_i value, and the worst rank is obtained based on R_i value.

Step 6: Calculate VIKOR value Q_i. The value is calculated for each i based on the following equations:

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*} \right] + (1 - v) \left[\frac{R_i - R^*}{R^- - R^*} \right], \tag{15}$$

$$S^- = \max_i S_i, \qquad S^* = \min_i S_i, \tag{16}$$

$$R^- = \max_i R_i, \qquad R^* = \min_i R_i, \tag{17}$$

where, v refers to the strategy of agreed majority of criteria or maximum group desirability. According to the agreement level of group, a decision-maker can be selected. In this study, v is equal to 0.5.

Step 7: Ranking options based on Q_i values. In this step, based on Q_i values calculated in Step 6, options are ranked and a decision is made. Ranking is done in such a way that every option with low Q_i value has a higher rank, provided that the following conditions are met:

- First condition (acceptance feature):

$$Q(A^2) - Q(A^1) \geq DQ, \tag{18}$$

$$DQ = \frac{1}{m - 1}, \tag{19}$$

where A^2 is ranked second based on Q criterion, and A^1 is the best option with the lowest Q value and m options.

- Second condition (stability of acceptance in decision-making): Option A^1 should have the best rank in S or R.

If one of the above-mentioned conditions is not provided, a set of compromise solutions can be proposed as follows:

1. Options A^1 and A^2 hold, if only the second condition is not provided.
2. Options A^1, A^2, and A^m hold, if the first condition is not provided.

A^m is an option in position m, for which the $Q(A^2) - Q(A^1) \geq DQ$ equation is true.

4. Results

In this section, the results obtained from research data are analyzed. The data collection is done by 8 experts active in the field of management and supply department of Saipa Corporation with work experience more than 12 years. According to the collected data, the best and worst criteria were firstly specified by experts and, then, through solving the mathematical model proposed in BWM, the final weight of criteria was determined. Then, by using VIKOR method, the decision matrix was created and, after normalization of the data in this matrix, the final decision was made. To this end, the final research results are presented here.

4.1. Determining the weights of criteria

In this section, the results of analysis taken in this study are presented and, following the distribution and collection of BWM questionnaire, the best and worst criteria have been specified. In order to meet and valuate the criteria, the opinions of an expert committee in the field of energy and environment are utilized. The best criterion identified by each respondent is the most significant criterion affecting supplier selection, and the worst criterion identified by each respondent can be the least significant option based on the opinions of the experts. The best and worst criteria presented by experts are observed in Table 4.

After determining the best and worst criteria according to experts, the other best criteria vectors are presented in Table 5.

Similarly, the priorities of other criteria are also determined compared to the worst criterion. The information has been also obtained through the distribution and collection of BWM questionnaire; therefore, the respondents were asked to determine the priority of other criteria compared to the worst criterion. Hence, the other criteria including the worst vector are presented in Table 6.

Finally, the BWM method was used to determine the consistency results of paired comparisons and the weights of criteria affecting supplier selection. The weights of the main criteria are obtained by solving the linear best-worst model for 8 respondents (experts) using GAMS software-24.3 and CONOPT solver. The weights include mean weights obtained for each criterion shown in Table 7 in a unit weighted vector.

ξ^{L^*} represents consistency of comparisons and, as observed in Table 7, comparisons are of high consistency, since the value for comparisons is close to 0 [41]. Moreover, criteria including transportation flexibility,

Table 4. The best and worst criteria identified by experts.

Criterion	Identified as the best criterion	Identified as the worst criterion
Product flexibility (C_1)	5, 1	–
Transportation flexibility (C_2)	3, 7, 8	–
Resource flexibility (C_3)	–	1, 4, 5
Environmental performance (C_4)	2, 4	–
Green technology (C_5)	–	–
Green design (C_6)	6	–
Agility in operating systems (C_7)	–	2, 7
Market agility (C_8)	–	3, 8
Logistics agility (C_9)	1, 8	–

Table 5. The other best criteria vectors.

Experts	Best criterion	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Expert 1	C_1	1	3	9	2	4	2	3	2	4
Expert 2	C_4	4	2	3	1	2	2	8	3	4
Expert 3	C_2	2	1	4	2	2	3	2	9	4
Expert 4	C_4	2	3	8	1	4	2	2	3	5
Expert 5	C_1	1	2	9	3	2	2	3	4	2
Expert 6	C_6	2	3	2	4	2	1	3	3	9
Expert 7	C_2	3	1	2	2	3	2	9	2	5
Expert 8	C_2	3	1	3	2	2	5	2	8	2

Table 6. The other worst criteria vector.

	Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**	**Expert 7**	**Expert 8**
	Worst criterion							
Criterion	C_3	C_7	C_8	C_9	C_3	C_9	C_7	C_8
C_1	9	2	2	2	9	2	2	2
C_2	2	3	9	4	2	2	9	8
C_3	1	2	3	1	1	3	2	2
C_4	2	8	5	8	5	4	3	3
C_5	3	3	2	2	4	5	5	5
C_6	4	2	2	5	3	9	2	3
C_7	3	1	2	3	2	3	1	3
C_8	2	4	1	2	3	2	4	1
C_9	2	2	3	2	3	1	2	2

Table 7. Weights of criteria affecting supplier selection.

	Respondents (experts)								
Criterion	**Ex 1**	**Ex 2**	**Ex 3**	**Ex 4**	**Ex 5**	**Ex 6**	**Ex 7**	**Ex 8**	**Mean weights**
Product flexibility (C_1)	0.256	0.072	0.103	0.106	0.253	0.100	0.097	0.091	0.135
Transportation flexibility (C_2)	0.099	0.139	0.256	0.097	0.104	0.095	0.246	0.236	0.159
Resource flexibility (C_3)	0.033	0.096	0.077	0.034	0.029	0.129	0.101	0.091	0.074
Environmental performance (C_4)	0.107	0.249	0.103	0.251	0.099	0.071	0.129	0.130	0.142
Green technology (C_5)	0.074	0.139	0.103	0.072	0.149	0.143	0.097	0.0137	0.114
Green design (C_6)	0.149	0.105	0.103	0.145	0.133	0.243	.101	0.055	0.102
Agility in operating systems (C_7)	0.099	0.033	0.154	0.140	0.099	0.095	0.028	0.130	0.097
Market agility (C_8)	0.107	0.096	0.026	0.097	0.075	0.095	0.145	0.031	0.084
Logistics agility (C_9)	0.074	0.072	0.077	0.058	0.060	0.029	0.058	0.099	0.066
ξ^{L^*}	0.041	0.038	0.051	0.039	0.046	0.043	0.044	0.038	0.043

environmental performance, and product flexibility are more significant than other criteria.

4.2. Ranking the proposed options for supplier selection

In this section, by applying the VIKOR multi-criteria decision making technique, the suppliers are ranked. Hence, after the required data collection, the option-criterion decision matrix is obtained, as shown in Table 8. According to the different scales of functional factors, the data should be normalized. The dataset in this case can be considered in two forms of the best maximum value and the best minimum value.

Here, the above-presented option-criterion decision matrix should be normalized. In Table 9, the normalized matrix is reported.

Finally, Table 10 shows the criteria such as usefulness (S_i), unfortunate (R_i), and VIKOR (Q_i) and ranking of the proposed options for supplier selection.

According to Table 10, Suppliers 2, 11, 12, 14, 3, 15, and 10 are selected as the best suppliers because of their lower Q_i value compared to others. An important note is $Q_2 = 0$. The reason for this issue can be $S_2 = S^*$ and $R_2 = R^*$. In fact, for the second option, the usefulness and unfortunate values are exactly equal to the minimum value among all options.

5. Conclusion

One of the underlying issues in the field of SCM is selecting raw material suppliers. Lack of good supplier can cause disruption in cost, time, and quality of raw materials and can also create a problem in supply chain efficiency. Since there are a limited number of

Table 8. Option-criterion decision-making matrix.

Option-criterion	Criteria affecting supplier selection								
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Supplier (1)	5.0	4.0	4.9	7.0	4.8	7.5	8.2	6.4	4.3
Supplier (2)	6.2	6.6	6.1	5.7	5.4	7.3	7.5	5.7	7.1
Supplier (3)	4.0	7.2	8.4	6.9	5.6	6.9	4.2	6.0	5.5
Supplier (4)	4.6	7.1	4.5	5.0	7.4	3.8	4.6	6.1	7.4
Supplier (5)	3.6	7.0	8.5	5.4	3.2	8.3	7.0	5.5	4.2
Supplier (6)	8.4	5.3	4.1	4.8	6.3	3.9	5.4	7.5	4.3
Supplier (7)	6.8	8.5	3.8	4.0	4.3	4.4	4.3	7.1	5.5
Supplier (8)	7.6	4.5	7.3	7.7	4.8	8.1	4.4	4.3	3.9
Supplier (9)	6.9	7.3	6.1	3.9	5.5	5.4	4.3	7.5	7.2
Supplier (10)	5.2	4.6	4.9	7.0	6.2	8.5	4.5	6.2	7.8
Supplier (11)	6.3	6.5	6.9	5.3	6.9	4.9	6.1	8.3	5.5
Supplier (12)	7.2	5.4	5.8	6.0	7.1	7.3	6.7	6.6	3.6
Supplier (13)	8.3	3.7	7.3	4.9	4.1	6.1	6.6	7.6	7.4
Supplier (14)	6.3	7.5	8.3	5.0	5.9	8.2	6.1	4.8	4.0
Supplier (15)	8.1	6.9	8.1	5.0	4.9	5.9	3.6	5.9	4.9

Table 9. Normalized matrix.

Option-criterion	Criteria affecting supplier selection								
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Supplier (1)	0.295	0.220	0.278	0.414	0.314	0.405	0.493	0.370	0.277
Supplier (2)	0.365	0.365	0.347	0.338	0.355	0.397	0.448	0.328	0.463
Supplier (3)	0.238	0.397	0.477	0.413	0.368	0.372	0.252	0.347	0.356
Supplier (4)	0.269	0.392	0.259	0.298	0.488	0.204	0.274	0.352	0.484
Supplier (5)	0.215	0.383	0.483	0.322	0.211	0.451	0.420	0.314	0.272
Supplier (6)	0.494	0.289	0.234	0.287	0.419	0.212	0.321	0.433	0.283
Supplier (7)	0.400	0.465	0.216	0.239	0.283	0.240	0.260	0.406	0.360
Supplier (8)	0.448	0.246	0.416	0.460	0.319	0.439	0.266	0.245	0.252
Supplier (9)	0.405	0.402	0.350	0.230	0.365	0.294	0.259	0.428	0.467
Supplier (10)	0.309	0.255	0.281	0.416	0.409	0.460	0.267	0.357	0.508
Supplier (11)	0.370	0.359	0.393	0.315	0.458	0.266	0.365	0.478	0.359
Supplier (12)	0.424	0.295	0.334	0.357	0.467	0.397	0.404	0.378	0.235
Supplier (13)	0.486	0.295	0.334	0.357	0.467	0.397	0.404	0.434	0.484
Supplier (14)	0.371	0.415	0.473	0.295	0.386	0.446	0.363	0.275	0.258
Supplier (15)	0.478	0.379	0.465	0.299	0.323	0.321	0.217	0.340	0.320

companies in the automotive industry in Iran and there is no high competitiveness, part of the demand may not be met well, which leads to customer dissatisfaction in case of improper delivering. Therefore, due to suitable criteria, suppliers should be selected using management approaches. In this regard, each expert of organizations has special opinions about the advantages and hedges of options. This can prevent traditional selection of the best option due to the criteria and sub-criteria. One of the best tools to rank options based on different criteria is using multi-criteria decision-making methods. In this study, existing factors in supplier selection to supply raw materials of Saipa Corporation are considered as the criteria for selecting the best option. Accordingly, the existence of an efficient method is essential to measuring limitations of suppliers and requirements of the organization to analyze and make decisions on selecting the best and the most effective solution. In

Table 10. Results of criterion including usefulness (S_i), unfortunate (R_i), VIKOR (Q_i) and ranking proposed options.

Option	S_i	R_i	Q_i	Rank
Supplier (1)	0.519	0.159	0.784	14
Supplier (2)	0.397	0.078	0.000	1
Supplier (3)	0.455	0.124	0.413	5
Supplier (4)	0.549	0.109	0.595	8
Supplier (5)	0.534	0.135	0.695	12
Supplier (6)	0.548	0.114	0.621	9
Supplier (7)	0.578	0.142	0.846	15
Supplier (8)	0.498	0.142	0.632	11
Supplier (9)	0.485	0.148	0.629	10
Supplier (10)	0.456	0.136	0.481	7
Supplier (11)	0.403	0.0.93	0.099	2
Supplier (12)	0.414	0.110	0.223	3
Supplier (13)	0.477	0.170	0.727	13
Supplier (14)	0.432	0.106	0.250	4
Supplier (15)	0.494	0.111	0.450	6

this study, an approach based on BWM and VIKOR methods is used to select the final options. In this approach, at first, by using BWM, each criterion and sub-criterion was weighted and, then, by using VIKOR method, final ranking was performed. The reason for choosing BWM to weight criteria can be the existence of the mathematical model, leading to the optimal allocation of weights. However, VIKOR method is also considered as the final proposed approach to the final determination of criteria because of a developed decision matrix. The combination of the two methods can provide conditions for a suitable selection of final options. According to the calculations, due to the proposed process and existing information about existing criteria of the studied company, the best and the most efficient solution can be the selection of Suppliers 2, 11, 12, 14, 3, 15, and 10. Selecting these options encompasses some advantages for the company including enhanced efficiency level of environmental factors and enhancement of the flexibility level based on desired standards by the manufacturer. According to the analysis and the correlations of criteria and based on the obtained results, it would be better for scholars to analyze the dependence of criteria and investigate the correlation between the options and criteria so that better results can be obtained in future studies.

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