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Research Article

A Fuzzy Multi-Objective Mathematical Model for Supplier Evaluation in a Reliable Supply Chain considering Different Risk Levels

Yuanyuan Tian,[1] Saeed Bahrami ,[2] and Farshad kaveh[3]

[1]*College of Humanity and Management, Xi'an Traffic Engineering Institute, Xi'an, Shaanxi Province, China*
[2]*Department of Educational Science, Farhangian University, Tehran, Iran*
[3]*Department of Industrial Engineering, Islamic Azad University, Najafabad Branch, Najafabad, Iran*

Correspondence should be addressed to Saeed Bahrami; s.bahrami@cfu.ac.ir

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One of the advantages of sustainable competition for manufacturing systems is to make supply chain activities more efficient and effective. One of the major parts of these activities that can save a lot of costs is careful outsourcing. In this study, an approach based on decision-making policies in order to select suppliers and allocate order volume to them is introduced. The main contribution of this research is a comprehensive approach for optimizing both supplier evaluation and order allocation. In this regard, first, based on the evaluation, 39 key indicators were identified to evaluate the suppliers, and based on the content analysis, 25 key indicators were screened based on the Lavache method. Next, based on the fuzzy Delphi method, 11 indicators were selected from among the 25 key effective indicators. Finally, the Best-Worst Method (BWM) and a robust multi-objective formulation are proposed to find the weight of the effective criteria and the optimal order allocation to suppliers, respectively. Moreover, it is proved that the company under study faces a variety of suppliers and there is a need to analyze key indicators such as exchange rate changes and ease of communication. Based on the BWM results, it was shown that the exchange rate change trend with a weight of 0.24 is in the first place, and the quality system support index with a weight of 0.12 is in the second place. Moreover, based on the results of the proposed robust multi-objective mathematical model, it was revealed that in order to maintain the resilience of suppliers, the total demand should be distributed among all suppliers and the second supplier with a volume of 3600 units of raw materials has the largest share in delivering the required demand.

1. Introduction

Nowadays, supply chains play a key role in the global economy. The competition between companies has given way to competition between supply chains. In other words, a network of companies is responsible for converting raw materials into final products and delivering them to the customer. This network of entities is responsible for various supply, production, storage, and distribution processes known as a supply chain. Regulators widely recognize the requirements for sustainable development. Organizations and consumers can act according to the definition of sustainable development to meet the current needs of society without compromising the ability of future generations to meet their needs. Therefore, a global perspective is needed to improve economic growth in sustainable development by emphasizing the relationship between the environment and social components [1].

One of the advantages of sustainable competition for manufacturing systems is more efficient and effective supply chain operations. One of the significant parts of these activities that can save many costs is the careful outsourcing of the organization's supplies [2]. Outsourcing the management of logistics activities, in addition to being an important resource for creating competitive advantages, can also provide customer satisfaction and meet their needs. Moreover, logistics network design integration is also of great importance for this reason [3]. Supply chain outsourcing has evolved as a new area of management research to help companies recognize potential resources and overcome operational and strategic challenges.

In recent years, evaluating the supply chain performance has attracted attention in the field of production and operations management [4, 5]. On the other hand, outsourcing evaluation and supplier selection policies are a challenge in which all areas of success and failure of organizations depend on the success or failure of outsourcing [6]. In such cases, decision-makers must use an optimal approach to allocate their available resources to achieve the best results.

Failure risk is one of the most likely situations in evaluating suppliers based on companies' incorrect supply policies [7]. Therefore, supply chain management is one of the components of competitive strategies for organizational productivity and profitability. Managers in many industries, especially manufacturing sectors, try to manage the supply chain better and evaluate their performance continuously [6].

In the supply chain, evaluating the performance of suppliers is one of the major challenges. One of the most important tools is a distinctive framework for evaluating suppliers by considering effective indicators using decision-making techniques. Therefore, outsourcing the management of the entire supply chain is a very difficult and challenging task. An organization will be economically efficient if it is technically and professionally efficient. Supply chain management coordinates all of these activities such that customers can obtain quality products and reliable services at a minimal cost.

In this study, a mathematical model is provided for evaluating the suppliers of a multi-level supply chain as well as assigning orders to qualified suppliers. In this regard, first, the effective indicators in evaluating the suppliers are extracted using the fuzzy Delphi analysis. Next, the best and worst indicators to evaluate supply chain outsourcing components are implemented using the BWM. It should be noted that the best and most qualified suppliers which are selected from the BWM are put as the set of available suppliers for assigning orders. Finally, a multi-objective model is proposed to find the optimal order allocation in the supply chain.

The main contribution of this research is based on presenting an integrated model of supplier evaluation and order volume allocation in the space of demand and supply uncertainty, as well as identification and selection of supply chain indicators based on literature review and the fuzzy Delphi analysis. According to the review of research literature, in most research items, the exploratory factor analysis method and classification of factors have been done by the PCA method, and the innovation considered in this section is the use of the fuzzy Delphi analysis, which according to the evaluation of incompatibility of opinions is highly accurate. In addition, to the best of the authors' knowledge, no research has been done in the field of order allocation in the supply chain, taking into account the demand uncertainty and implementing robust counterpart formulation for dealing with demand uncertainty.

2. Related Works

Supplier selection is an important issue for most supply chains. This issue was assessed first by Hulme [8] in 1963. In recent years, the importance of supplies in supply chain management has cleared for most real cases [9]. In order to facilitate the process of developing a supply chain, it is necessary to deal with the uncertainty in the raw material supply [7]. Therefore, it can be claimed that the right choice of suppliers can help the supply chain's success and, in the long, have a significant impact on the reliability of the final products [8].

Choosing the right supplier requires the consideration of several criteria. Decision-making is an issue that human beings have faced since its creation. Eventually, with the advancement of science and technology, human needs have changed dramatically. As it turns out, each person is faced with a variety of issues during the day and night that they must make the best decision. The science of decision-making has grown in various disciplines, including management, engineering, and operations research with scientific management. As society becomes more complex, goals become more numerous and conventional [5]. It is always necessary for organizations to strike a balance between their many conflicting goals, such as economic growth and efficiency. Industrial or commercial companies have also realized that they need to set several goals to make better decisions.

From the set of operations research techniques, decision-making techniques with multiple criteria are responsible for solving such problems in decision-making. In models such as linear programming, integer programming, nonlinear programming, and major classical operations research models, only one criterion such as profit, cost, efficiency, time, etc., is considered, while in multi-criteria decision-making models, several criteria are used simultaneously [6, 10].

The importance of supply chain management lies in the definition of the supply chain. Pourghader chobar et al. [7] define a supply chain as follows: Supply chain is a set of organizations that are divided into upstream and downstream organizations and seek to create value for the end customer through a product or service and through various activities and processes. The supply chain includes all activities related to the flow of products and the conversion of materials, from the stage of preparation of the raw material to the stage of delivery of the final product to the consumer. More broadly, a supply chain consists of at least two or three organizations legally separate and interconnected by material, information, and financial flows (Figure 1). These organizations can be organizations that produce end products and components and even include logistics service providers and the end customer themselves. Reference [11].

The purpose of supply chain management is to improve the efficiency of the supply chain process such that the right product reaches the customer in a timely manner and at the lowest cost. The belief that supply chain management can lead to better customer response and ultimately greater profitability has led many managers to consider supply chain

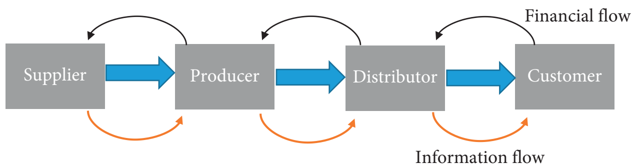

Figure 1: The flows in a supply chain.

management. Saeedi Mehrabad et al. [12] have identified the drivers of organizations toward supply chain management as follows: the need for improvement activities, increasing the level of outsourcing, supply chain complexity, the importance of global trade, increasing globalization, competitive pressures, increasing shipping costs, and the need for inventory management. Many authors have worked on green supply chain management as one of the most popular emerging environmental management methods. The emergence of this type of literature dates back to 1990 when companies became aware of the environment and supply chain management with the advent of environmental management [13].

Prior to 2000, there were few papers on logistics management, green supply chain management, and the environment, but later much research was done on environmental issues and threats to human life. Due to global warming and oil price fluctuations, more emphasis was placed on environmental protection, which led to much research into the development of green supply chain management concepts and theories. Today, many research efforts focus on examining the relationship between green/environmental factors and organizational/environmental performance. Green supply chain management advocates productivity and synergy between partners and facilitates environmental performance. Waste minimization and cost saving have attracted increasing interest from researchers and operations and supply chain management. Green supply chain management has emerged as an important new model for companies to achieve profit goals and market share by reducing their environmental impacts and risks along with increasing their ecological efficiency [6–9].

Mirhedayatian et al. [13] proposed the Analytical Hierarchical Process of Data Envelopment Analysis (DEAHP) to evaluate the suppliers in a green supply chain. To reduce the damage to the environment, Shin et al. [14] developed their own research model. Lee et al. [15] examined the effects of strategic risk analysis on outsourcing ICT services in California hospitals from 1997 to 2007. The results of the research showed that outsourcing risk analysis has a positive and significant effect on productivity.

Nowadays, it is essential for companies to select the right suppliers to create a space in the business environment. Therefore, choosing a supplier is an important issue for companies. Wan et al. [16] examined a type of supplier selection problem with two-level criteria and proposed a hybrid method that was a hybrid ANP and ELECRE II method. According to the Abdel-Basset study, companies are likely to respond well to unexpected events by considering and applying the appropriate risk reduction strategy [17].

Subsequently, uncertainty and ignorance, in reality, are the key factors that make it challenging to control risks. Hence, risk analysis, reduction, and control provide recommendations for appropriate decision-making. Lo et al. [18] presented a model for obtaining the weight of benchmarks and a modified fuzzy TOPSIS for calculating supplier ratings. This study used the fuzzy MODM model to assign the order to eligible suppliers. The important point in this paper is that this study used the TOPSIS technique and fuzzy theory to strengthen the analytical model due to the uncertainty of managers' opinions. After consulting with company executives, four objective functions are defined: cost, delivery performance, product quality, and total profit. Tong et al. [19] proposed the PROMETHEE II for evaluating the sustainability of the suppliers. They implemented the proposed method for a variety of small- and medium-sized enterprises in China. Liu et al. [20] assessed a new multi-criteria decision-making method, which considers the bi-directional influence relation of the criteria, consensus, and the psychological factors of decision-makers. They implemented this method for evaluating emergency medical suppliers.

As mentioned in the literature review, most of the research in the field of supply chain outsourcing is based on chain efficiency and the logic of the research method of data envelopment analysis to evaluate the performance of suppliers, or most of them are selected by selecting indicators.

The research gap observed in the supply chain research is related to the lack of a comprehensive approach for optimizing supplier evaluation as well as order allocation. To cover this part of the research gap, the fuzzy Delphi and BWM methods have been used to evaluate and select the most effective components using expert opinions. Another research gap observed in the research is the non-application of uncertainty conditions in decision-making. In this regard, a robust counterpart formulation is proposed to find optimal order allocation under demand uncertainty.

3. Methodology

In this research, the evaluation and selection of suppliers to supply the required items are made in two stages. In the first stage, the initial evaluation of potential contractors is done, and the desirable and qualified contractors are included in the list of qualified ones. In the second stage of the main evaluation, to determine the volume of supply and order from each final supplier, in this stage, the multi-objective decision-making method is used, and then the multi-objective decision-making model is used to optimize and assign the order to suppliers, which is the main focus of the present study. Figure 2 shows the development framework of the combined MCDM and MODM model in this research.

In the first stage, searching reputable scientific sites and reviewing existing scientific texts on criteria and indicators, evaluation, and selection of suppliers were performed. After selecting the criteria, managers and experts in the fields of procurement, procurement, quality, research and development, and engineering were asked to rate each index according to the importance of the indicators, and on a fuzzy

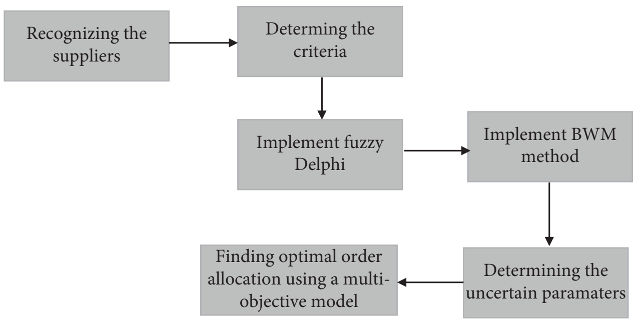

Figure 2: The proposed framework based on MCDM and MODM to evaluate the suppliers.

scale based on the fuzzy calculating the average scores, the indicators that had an average score of "above 3" were identified and selected. In order to receive the opinions of experts, the number of samples should be determined based on the number of the existing community of experts; in this study, due to the limited number of members, the counting method was used, and the opinions of all of them were used.

In order to obtain the necessary assurance from the accuracy and validity of the opinions received from the experts, the reliability test is implemented. In this research, an integrated model has been developed to analyze and select the most appropriate suppliers. The proposed model is a hybrid model that takes into account different ideas while considering different criteria. The proposed model evaluates the suppliers of raw materials, taking into account various constraints (including existing constraints and systemic constraints), and finally assigns the optimal order assignment to each of them.

The research method can be divided into two main parts. The first part involves setting quantitative and qualitative criteria and using the fuzzy Delphi and BWM techniques to weigh the criteria and evaluate the suppliers. The second part is to identify the application and system constraints and combine the results of the first phase with the mathematical model in order to assign the optimal order quantity to each supplier.

3.1. Screening Indicators Based on the Fuzzy Delphi Method. At this stage, using the fuzzy Delphi technique, the indicators are refined and selected. The Delphi expert panel is a mix of 15 experts. Although experts use their mental faculties and abilities to make comparisons, it should be noted that the process of numerical quantification does not fully reflect human thought. The use of fuzzy sets is more compatible with linguistic and sometimes ambiguous human explanations, and hence it is better to use fuzzy numbers to transform mental and linguistic concepts into small quantities in the real world. In this study, triangular fuzzy numbers have been used to convert mental and linguistic concepts into quantitative values.

A fuzzy number is a specific fuzzy set as $\tilde{A} = x \in R/\mu\_\tilde{A}(x)$ in which x accepts the real values of the member of the set R and its membership function is $\mu_{\tilde{A}}(x)$.

Table 1: Verbal fuzzy numbers.

Fuzzy number	Verbal phrase
(0.25, 0, 0)	Very low importance
(0.5,0.25, 0)	Low importance
(0.25, 0.5, 0.75)	Medium importance
(0.5,0.75,1)	Very important
(0.75, 1, 1)	Very important

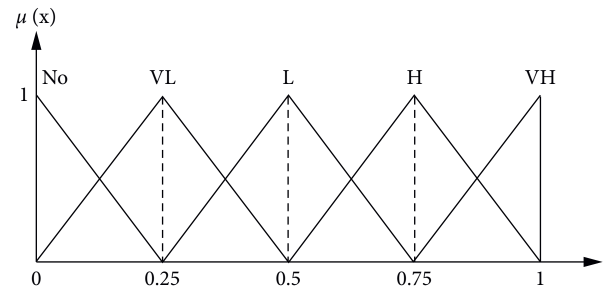

Figure 3: Triangular fuzzy numbers for verbal phrase.

A triangular fuzzy number A is defined by (1) with the membership function of linear fractions $\mu_{\tilde{A}}(x)$.

$$\mu_x(x) = \begin{cases} \dfrac{(x-l)}{(m-l)} l \le x < m, \\ l\, x = m, \\ \dfrac{(u-x)}{(u-m)} m < x \le u, \\ 0 \text{ otherwise}, \end{cases} \quad (1)$$

where l represents the lower bound, m represents the most probable state, and u represents the upper bound and can be represented as a triangular fuzzy number (l, m, u).

In this research, verbal variables have been fuzzy to determine the importance of indicators according to the triangular fuzzy numbers in Table 1 and Figure 3.

After collecting the data, the fuzzy mean of the n respondents' comments is calculated using the usual methods. Then, decompression operations and determining the importance of the indexes are used, and the indexes with a value lower than the average value are removed.

3.2. Validity of the Identified Indicators for Analyzing the Suppliers. To evaluate the validity of the indicators, the Lavoshe method has been applied. In order to calculate this index, the opinions of experts in the field of test content were used, and by explaining the test objectives to them and providing operational definitions related to the content of the questions, they were asked to rate each question based on Likert's three-part spectrum. "Is necessary", "item is useful but not necessary," and "item is not necessary". Then, according to (2), the content validity ratio is calculated.

Table 2: Minimum acceptable CVR value for content validity.

CVR	Number of experts	CVR	Number of experts	CVR	Number of experts
0.37	25	0.59	11	0.99	5
0.33	30	0.56	12	0.99	6
0.31	35	0.54	13	0.99	7
0.29	40	0.51	14	0.75	8
		0.49	15	0.78	9
		0.42	20	0.62	10

$$\mathrm{CVR} = \frac{N_e - N/2}{N/2}, \tag{2}$$

where N is the total number of specialists and Ne is the number of specialists who have selected the necessary option. Therefore, based on the number of experts who evaluated the questions, the minimum acceptable CVR value is calculated based on Table 2. The amount of CVR calculated for them should be less than the desired amount, according to the number of experts evaluating the question, because according to the index, they do not have acceptable content validity and should be excluded from the test.

3.3. Evaluation of the Suppliers Using the BWM Method. The best-worst method is used to solve multi-criteria decision-making problems. The steps of the BWM method to obtain the weight of the criteria can be described as the following steps:

Step 1: Specifying the set of criteria: In this step, the criteria $\{C_1, C_2, \ldots, C_n\}$ that should be used in the decision are considered.

Step 2: Identifying the best and worst criteria.

Step 3: Determining the performance of the best benchmark against other ones using numbers between 1 and 9. The results of the best criterion compared to the other criteria are in the form of equation (3);

$$A_B = a_{b1}, a_{b2}, \ldots, a_{bn}. \tag{3}$$

where a_{bj} indicates the performance of the best criterion (B) relative to criterion j. Obviously $A_{bb} = 1$.

Step 4: Determining the performance of all criteria for the worst case using numbers 1 to 9. The formula for the results of comparisons of criteria to the worst criterion can be defined as equation (4):

$$A_w = a_{1w}, a_{2w}, \ldots, a_{nw}. \tag{4}$$

where a_{jw} indicates the performance of criterion j relative to the worst criterion (W). Obviously, $A_{ww} = 1$.

Step 5: Finding the optimal weights: The optimal values for the criteria are unique, which I will have for each pair of W_j/W_w and W_B/W_j (equation (5)):

$$\begin{aligned} \frac{W_B}{W_j} &= a_{Bj}, \\ \frac{W_j}{W_w} &= a_{jw}. \end{aligned} \tag{5}$$

Table 3: The notation of the proposed mathematical model.

W_j	The weight of goal j
d_j^-	Negative deviation from goal j
d_j^+	Positive deviation from goal j
b_j	The defined level of goal j
A	The weighted sum of deviations from goals
α	Penalty for non-compliant production of suppliers
β	Delivery schedule penalty
a_{ji}	Technical coefficients
Z_j	Maximum (minimum) value of the goal j
C_i	Price of raw materials supplier i
R_i	The cost of transporting the product of the supplier i
K_i	Supplier i capacity
$\widetilde{D}$	Total company demand (under uncertainty)
L_i	Timely delivery point of supplier i
F_i	After-sales service of supplier i
Fl_i	Level of flexibility in improving the quality of the supplier i
x_i	Order quantity from supplier i

To satisfy these conditions for all j, a solution must be provided that minimizes the absolute value of the maximum difference. Given that the weights are non-negative and summable, the problem is expressed as a nonlinear model according to (6):

$$\begin{aligned} &\mathrm{Min}\, \varepsilon^* \\ st\colon\ & \left| W_B - a_{Bj} W_j \right| \le \varepsilon^*, \quad \forall j, \\ & \left| W_j - a_{jw} W_w \right| \le \varepsilon^*, \quad \forall j, \\ & \sum_j W_j = 1, \\ & W_j \ge 0; \quad \forall j. \end{aligned} \tag{6}$$

After solving the above model, the optimal values of weights (W_1^*, W_2^*, $\ldots$, W_n^*), and the value of ε^* will be obtained. Then, using ε^*, a compatibility rate is introduced, and it will be determined that larger values for ε^* will lead to higher compatibility rates and lower reliability of the comparisons. Finally, the value of the compatibility rate is obtained using ε^* and the related compatibility index is obtained using (7):

$$CR = \frac{\varepsilon^*}{CI}, \tag{7}$$

where CR represents the value of the compliance rate and CI represents the corresponding compliance index. An incompatibility rate less than 0.1 would be desirable.

3.4. Mathematical Model of Order Allocation to the Suppliers. After evaluating the suppliers and selecting them, in this step, using the ideal planning method and mathematical model, the volume of orders is allocated, which is uncertain. The corresponding symbols are defined according to Table 3.

It must be purchased from different suppliers to supply the required raw material. In purchasing from these suppliers, their important features in modeling should be considered. Moreover, the company should be restricted from purchasing from any of the suppliers. For example, the product of each of the suppliers has positive and negative qualitative characteristics that try to include the important characteristics in the proposed mathematical model. The objective function (8) minimizes the distance of the goals from the defined ideal value, and the ideal constraint will keep the value of each goal close to the ideal.

$$\text{Min } A = \sum_{j=1}^{m}\left(w_j d_j^- + w_j d_j^+\right),$$
$$st\colon \sum_{i=1}^{n} a_{ji}x_i + d_j^- - d_j^+ = b_j \quad \forall\{j = 1,2,\ldots,m\}, \forall\{i = 1,2,\ldots,n\}. \tag{8}$$

The constraints of this model can be divided into ideal constraints and systemic constraints. Ideal constraints include raw material purchase price, on-time delivery, flexibility in quality improvement, shipping cost, and quality. One of the important limitations, according to the analysis of this unit as well as the interviews conducted with the management, supply of materials, is the limitations of demand. Moreover, the important constraint of the supplier is the production capacity. All the mentioned constraints are entered into the model in the form of mathematical expressions.

(1) Purchase price: Considering that the amount of raw material supplied by the supplier i is equal to x_i and the price of the raw material supplied by the supplier i is equal to C_i, the ideal limit of the purchase price of the raw material is as equation (9).

$$\sum_{i=1}^{n} \alpha c_i x_i + d_1^- - d_1^+ = Z_1. \tag{9}$$

(2) Deliver time: Depending on the delivery time of each supplier's raw material, the ideal delivery time formulation should be minimized. If the delivering time score of the i-th supplier is indicated by L_i, then the delivery limit seeks to minimize all deviations from the delivery time which is shown in equation (10).

$$\sum_{i=1}^{n} \beta L_i x_i + d_2^- - d_2^+ = Z_2. \tag{10}$$

(3) After-sales service: One of the organizations' most important competitive advantages is to enable them for after-sales service. Suppliers' after-sales service allows the organization to increase customer satisfaction and respond to quality complaints. Therefore, organizations should try to select suppliers that maximize after-sales service. If we denote the level of flexibility in the volume of the i-th supplier by F_i, then the after-sales service constraint seeks to maximize the level of flexibility required in the optimal value shown in equation (11).

$$\sum_{i=1}^{n} F_i x_i + d_3^- - d_3^+ = Z_3. \tag{11}$$

(4) Flexibility in quality improvement: Considering that the raw material must be in accordance with the necessary technical and quality conditions, suppliers need to have the necessary flexibility in order to achieve the required technical and quality conditions; this can be a criterion also influenced by the selection of suppliers. If we denote the level of flexibility of supplier i in quality improvement with FL_i, then the limit of flexibility in quality improvement seeks to minimize all deviations from the flexibility of the suppliers, which is shown in equation (12).

$$\sum_{i=1}^{n} Fl_i x_i + d_4^- - d_4^+ = Z_4. \tag{12}$$

(5) Shipping cost: Considering the purchased quantity from the supplier $i\,(x_i)$ and the shipping cost of each ton of product of the supplier $i\,(R_i)$, the ideal limit of shipping cost is defined as equation (13).

$$\sum_{i=1}^{n} R_i x_i + d_5^- - d_5^+ = Z_5. \tag{13}$$

(6) Quality: Considering that suppliers must have the necessary quality to be able to attract the customer, this criterion can also be influenced in the selection of suppliers. If we denote the quality level of the supplier i by Q_i, then the quality constraint seeks to minimize all deviations from the quality of the supplier, which is shown in equation (14).

$$\sum_{i=1}^{n} Q_i x_i + d_6^- - d_6^+ = Z_6. \tag{14}$$

Supplier capacity constraints, raw material demand constraints, and non-negative variables' constraints were also defined as factors involved in the process as follows and added to the model. In this research, customers' demand is considered as an uncertain parameter. The reason for considering this uncertainty is the instability of the demand in most of the supply chains. In addition, supplying raw materials for production has a component of uncertainty in demand. Therefore, uncertainty in the amount of materials required is added to the model with the help of robust planning and an approach based on Bertsimas and Sim [21–23]. Therefore, the volume of demand required will be modified based on the Bertsimas and Sim robust approach [21–23].

$$
\begin{aligned}
&x_i \le K_i,\\
&\sum_{i=1}^{n} x_i \ge \widetilde{D} + \Gamma p + \sum_{i=1} q_i,\\
&p + q_i \ge \widehat{D} \quad \forall i \in I,\\
&x_i, d_j^-, d_j^+ \ge 0.
\end{aligned} \tag{15}
$$

The proposed model is developed based on the BWM method with the GP method, which is first evaluated based on the BWM method, and finally, using the GP method, the demand and order allocation to suppliers is optimized.

4. Numerical Results

After data collection, data analysis was performed using multi-criteria decision-making techniques, the fuzzy Delphi method, simulation logic, and mixed linear program optimization, compatible with the research method and the type of variables.

Based on the review of library articles and resources, a comprehensive list of 39 criteria of supply chain ranking indicators based on executive risks was introduced. Then, in order to finalize the criteria for selecting suppliers, their validity was evaluated through interviews with 15 experts by Roche Lavoche. Therefore, the most important indicators in the studied industry were introduced from among the found indicators, and suppliers were ranked according to the selected criteria.

According to the evaluation made in the first stage regarding the content validity of the research, out of the 39 identified indicators, only 25 indicators were approved (indicators with CVR values less than 0.49 are rejected), and in the next stage, screening, indicators by the fuzzy Delphi method were addressed. In the analyses performed, the deviation of experts' opinions is 0.07, which is appropriate in terms of the deviation of opinions, and good consistency is established. Table 4 presents the final refined indicators from the 39 identified indicators.

Next, the views of seven experts to assess the importance of the indicators identified in the field of the supply chain were examined through pairwise comparisons. It is worth mentioning that the fuzzy Delphi process has been performed in two stages because the rate of incompatibility of the comments was less than 0.1; hence, the validation of the comments has been approved. Finally, based on the evaluations made in the first step of screening, out of the 25 refined indicators, 11 indicators ($C1$, $C7$, $C8$, $C10$, $C11$, $C12$, $C18$, $C19C$, $C22$, $C23$, and $C24$) are selected.

Table 4: Indicators in the supply chain and supplier selection.

$C1$	Changes in exchange rates
$C2$	Change in interest rates
$C3$	Policy changes and tariffs
$C4$	Political change
$C5$	Changing consumer tastes
$C6$	Natural disaster
$C7$	Product reliability
$C8$	Shipping price
$C9$	Credibility and past performance
$C10$	Quality system support
$C11$	Compliance with safety/environmental regulations
$C12$	Flexibility in volume
$C13$	Production technology level
$C14$	Proximity of relationships
$C15$	Transparent communication
$C16$	Business maturity level
$C17$	Extra expenses
$C18$	Environmental programs and controls
$C19$	Existence of quality systems and continuous improvement
$C20$	Waste management
$C21$	Flexibility in product mixing
$C22$	Delivery reliability
$C23$	Ability to develop technology
$C24$	Ease of communication
$C25$	Consolidation of communications

4.1. Evaluating the Suppliers Using the BWM Approach. In order to evaluate the suppliers, according to the identification of the characteristics of the organization, the effective criteria in the evaluation of the suppliers were ranked. For this purpose, in the first step, 11 indicators specified in the previous step based on the method

BWM were examined. In the second step, according to a survey of organizational experts, the $C1$ index was evaluated as the best (most desirable, most important) and the $C22$ index as the worst (most undesirable, least important) criteria. In the third step, the importance of the best and worst criteria compared to other criteria was evaluated based on the opinions of key experts, and the geometric mean of the results of pairwise comparisons is shown in Table 5.

In the next step, the relationships between the criteria were developed in accordance with what is common in the BWM method, and the relevant model was planned and implemented in Lingo software. After solving the model, the optimal weight of the criteria as well as the value of the objective function (ε) is illustrated in Figure 4.

4.2. Order Allocation to Suppliers. According to the conditions of the organization under study, first, the supply chain processes were examined, and in this study, the supply situation of raw materials was evaluated. The results of this analysis indicated the existence of multiple suppliers for the supply of raw materials. In this route, the means of transportation according to the planning done by following the system (FIFO) to the place of suppliers and the level of demand required by the company are received. Therefore, the vehicles carry out the process of loading the raw materials according to the planned capacity and then return to the place of production. After weighing the indicators and identifying the constraints, the ideal planning model can be implemented in order to allocate the volume of demand (so that the importance of the criteria in supply can be applied as weights corresponding to the decision-making preferences), and it provides the basis. Table 6 shows the information on raw materials and suppliers.

In the ideal planning model, the ideal values are specified for each of the goals, and then the answer to the problem is

Table 5: Pairwise comparisons of the best and worst criteria based on the opinions of key experts.

Criteria	C1	C7	C8	C10	C11	C12	C18	C19	C22	C23	C24
Best	1	3.6	4.2	3	5.4	4.8	6.2	4	4.6	4.8	4.4
Worst	4.2	4.3	5.1	4.2	6.2	4.7	6.2	4	1	5.2	4.7

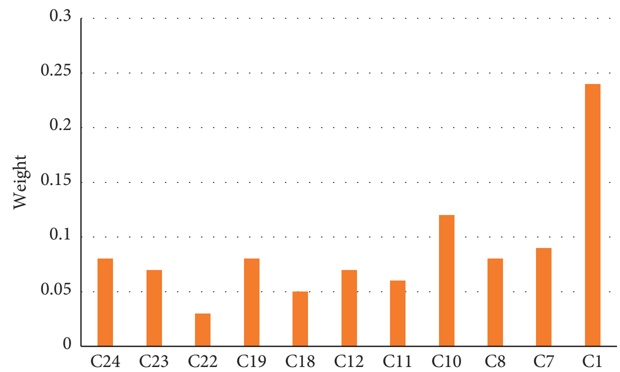

Figure 4: The optimal weight of criteria determined by the BWM.

Table 6: Details of the suppliers of raw materials.

Suppliers	Purchase price	Delivering time	After-sale service	Flexibility	Transportation cost	Quality cost	Capacity
Supplier 1	2.5	0.4	0.303	0.147	0.088	2300	4500
Supplier 2	2.41	0.256	0.259	0.369	0.295	2000	3600
Supplier 3	2.45	0.074	0.152	0.209	0.294	2100	2800
Supplier 4	2.35	0.135	0.229	0.096	0.318	1500	3300
Supplier 5	2.53	0.135	0.057	0.18	0.184	1400	3100

Table 7: Ideal values for set goals.

Criteria	Cost	Delivery time	After-sale service	Flexibility	Transportation cost	Quality
Objective value	28912	2856	11025	3192	2808	15890000

specified in such a way that the distance between the criteria and the goals is minimized. Due to the specified limitations, the values listed in Table 7 were considered as the goal for each goal.

Suppliers' prioritization of criteria is shown in terms of weights. These weights were placed as coefficients of variables in each ideal constraint that represents a goal, and at the same time, using the weights obtained from prioritizing the criteria in the model, each corresponding deviation was assigned its corresponding weight. System constraint parameters were also obtained by observing, interviewing, and reviewing information collected from different units of the company. This model was programmed and solved using LINGO software, the results of which are shown in Figure 5. As can be seen, orders have been assigned to different suppliers for the supply of materials, which is the result of the total purchase corresponding to the preferences of the decision-maker.

In this case, because of the ideal amount of price targets, timely delivery, flexibility in volume and quality improvement, transportation, and quality, the optimal amount is defined; the increase of the ideal does not make sense, and hence for positive criteria (such as quality) only a reduction of the ideal and for negative criteria (such as price) only an increase of the ideal is undesirable.

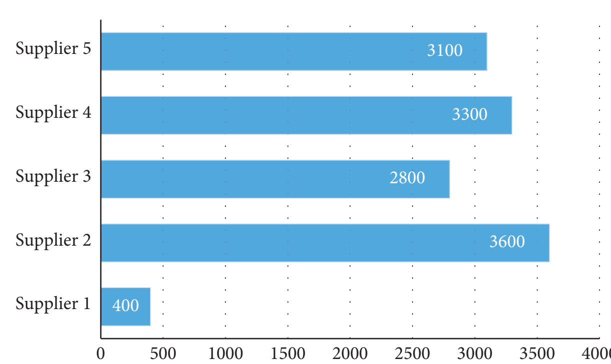

Figure 5: Optimal order allocation to suppliers.

5. Concluding and Future Directions

In today's global competition, economic and manufacturing firms have turned to supply chain management in order to gain a competitive advantage in order to gain more market share. The key issue in a supply chain is the coordinated management and control of all activities. Choosing a supplier is one of these issues, which is one of the most important strategies for the company to gain a competitive advantage. One of the most important reasons for highlighting the role of supplier selection for organizations is the shift of a paradigm. While companies initially sought to increase their supplier list in order to increase their bargaining power over prices, they are now trying to reach out to fewer suppliers that best meet their needs, i.e., establish a strategic alliance. This increases the efficiency and effectiveness of the company and its value chain through partnership communication and facilitating communication, providing faster and higher quality items. In this study, an approach based on decision-making policies was introduced to select suppliers and allocate order volume to them. Therefore, based on the evaluation, 39 key indicators for supplier evaluation were identified and based on content analysis, 25 key indicators were screened based on the Lavache method. According to the analysis, it was shown that the company has a variety of suppliers and needs to analyze key indicators such as exchange rate fluctuations and ease of communication. Then, based on the fuzzy Delphi method, among the 25 key indicators, 11 effective indicators in the study organization entitled "Exchange rate changes, product reliability, shipping price, support system quality, compliance with safety criteria, flexibility in volume, programs and environmental controls, quality system, delivery reliability, technology development capability, and ease of communication" were selected. Based on the calculations of the BWM method, it was shown that the exchange rate change with a weight of 0.24 is the most important factor, and the quality component of the support system with a weight of 0.12 was the second important factor.

Accordingly, it can be concluded that the issue of concern about exchange rate fluctuations and the quality of products supplied is a vital issue for the company under study, which should be well considered for the selection of suppliers. Furthermore, based on the multi-objective mathematical model, the inventory level required by suppliers was determined based on the optimization policy. According to the results obtained in the study, it was shown that in order to maintain the resilience of the company's supply chain, the total required demand is distributed among the five suppliers, and "Supplier No. 2" with 3600 units has the highest allocation and "Supplier No. 1" with 400 Units had the lowest amount of raw material allocation.

In this research, the managerial insights can be analyzed from several dimensions. First, it is considered that different indicators are applied in evaluating suppliers, which can help supply chain managers evaluate their suppliers from different aspects. Moreover, ranking suppliers and assigning orders to them simultaneously is a comprehensive approach to decide for supplying raw materials, which reduces any errors in decision-making. Therefore, this research can be used as a basis for managing relationships with suppliers in different supply chains. On the other hand, during the different stages of this research, new points were discovered, and at the same time, with the progress of this research, more ambiguities were created for researchers, which due to the existing limitations require more research. Finally, for the research of future researchers who intend to work in this field, some topics are suggested.

(1) To increase the accuracy and reduce uncertainty in prioritizing criteria and suppliers and assigning the optimal order amount to each supplier, it is suggested to combine this model with neural network models and genetic algorithm and compare it with the results of this study.

(2) Indicators of this research have been compiled according to the scope of research and appropriate to the company under study. It is suggested to provide a comprehensive model related to similar organizations and large companies by examining other similar companies.

(3) It is suggested that the indicators based on the conceptual model or structural model be hypothesized in similar companies to identify the supply management framework.

Data Availability

All data are available as a table in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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