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Evaluation and selection of suppliers in a supply chain based on multi-criteria decision-making model using fuzzy TOPSIS

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Abstract

In supply chain management, selecting suitable suppliers is a necessary strategic decision. Making these decisions is a complex process due to certain uncertain parameters, such as future demand. In this regard, the present study aims to evaluate and select suppliers in a supply chain based on a multi-criteria decision-making model using fuzzy TOPSIS. The research population consisted of experts from the purchasing and material supply unit in the detergent industry, who were selected using a purposive sampling method. According to them, the criteria for selecting suppliers were identified and weighted. The criteria were identified based on library studies and finalized with the experts' approval, and were then transformed into a pairwise comparison questionnaire. Within the framework of the Analytic Hierarchy Process (AHP), the opinions of the experts regarding the priority of the criteria were assessed using MATLAB software. By forming the decision-making matrix and using the fuzzy TOPSIS method, the final prioritization of the criteria was obtained. Based on the findings of the research, the criteria and sub-criteria for evaluating suppliers were classified into 4 main criteria (quality, protective, security, economic, and technical) and 28 sub-criteria. Quality factors were deemed the most important, followed by protective and security, technical, and economic criteria. Performance evaluation of each supplier group using the fuzzy TOPSIS method indicated that group A2 had the highest priority, followed by groups A4, A3, and A1 in that order. From the obtained results, it can be stated that the use of the fuzzy TOPSIS model is appropriate for the problem of supplier selection, especially in the final stage. Therefore, providing a flexible and cost-effective tool for supplier selection enables procurement managers to make quick decisions.

Keywords: Supplier selection, multi-criteria decision making, hierarchical process, fuzzy TOPSIS
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1 Introduction

One of the most obvious features of today's business environments is the complexity of these environments. In today's world, with the impact of globalization, the concept of competition has become one of the most important factors in businesses, and making appropriate strategic decisions is one of the major challenges for businesses to create

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competitive advantages in the future. Complex technologies, close economic competition and many other factors have made the decision about the future to be considered as a vital issue for business decisions [15]. In the real world, the existence of environments, complex relationships and communications, multiple criteria, uncertainties and incorrect information are the characteristics of many decision-making problems. For this reason, it is necessary to create an efficient and effective supply chain network to provide accurate, timely, quality and cost-effective services [3]. The supply chain network includes suppliers of raw materials, components, intermediate warehouses, assemblers, manufacturers, distributors, final warehouses, retailers and finally customers, along with physical, informational, and material flows between them, to achieve the goals of decision makers are designed. A well-executed supply chain strategy not only positively affects business operations but also strengthens overall competitiveness and enables sustainable success in terms of product quality and supplier engagement [16].

Considering that the performance of suppliers has a fundamental effect on the success or failure of the supply chain, supplier selection is considered a strategic task that is associated with reducing costs and increasing competitiveness in organizations [27]. It evaluates the providers based on different criteria. Due to the globalization of the market and the outsourcing initiative, many suppliers with different criteria are available today, which challenges the supplier selection process [3]. Normally, suppliers are evaluated based on cost, quality and service criteria. Each criterion usually includes several sub-criteria. Apart from cost, quality and service, other criteria such as supplier distance, on-time delivery are also considered in many supplier selection processes [22]. In addition, the needs of consumers may change over time, which can cause fluctuations in market demand [6]. Also, regulatory requirements to address environmental concerns have increased the pressure on businesses to adopt a sustainable supply chain. Therefore, various environmental criteria (for example, carbon emissions, product sustainability, use of environmentally friendly packaging materials) can also be included in the supplier selection criteria [36]. Some supplier evaluation criteria may conflict with other criteria (such as quality and cost). Therefore, it is challenging to find balance points among the conflicting criteria. Also, assessment of qualitative criteria can be misleading due to judgmental bias if a structured procedure is not followed. Therefore, choosing suitable suppliers is much more than scanning a series of price lists [32].

At present, in all businesses, the parallel presence of different units for the selection of suppliers can lead to receiving different opinions, and on the other hand, due to the lack of integrated and unified management, it can disturb the selection of suppliers. It is impossible to provide an ideal solution for designing a specific supplier selection process, because there is no one solution for everyone due to the variety of factors affecting the stakeholders' point of view, the existence of different expert decision makers [31]. Multi-criteria decision-making (MCDM) techniques have been introduced for this purpose. MCDM is a set of methods for evaluating alternatives in terms of multiple conflicting decision-making criteria [29]. Therefore, given a set of options (options) and several decision criteria, the objective of MCDM is to provide a choice, rank, describe, classify, sort, and order the options from the best option to the least preferred option. MCDM can provide an integrated framework for identifying, evaluating and prioritizing supplier selection and is a valuable tool for managers who want to think through the future dimension of decisions and actions. These techniques enable companies to make data-driven decisions that not only optimize costs but also increase product quality, customer satisfaction, and overall competitiveness. As a multi-criteria decision-making problem, various methods may be applied to supplier selection. The use of multi-feature methods has been considered by several authors, who have investigated their application separately or by combining techniques to solve this type of problem. Usually, at least two techniques are used together, one to estimate the weight of each criterion and the other to select the most suitable supplier by ranking the available options. Among many MCDM methods, researchers choose the most popular supplier selection method, namely, fuzzy set theory. It is combined with MCDM methods such as Analytical Hierarchy Process (AHP) and the technique for ordering priority based on similarity to the ideal solution (TOPSIS) [7]. Thomas L. Satty, AHP, is a method used in the decision-making process of complex problems. If the structure of the problem is incorrect, it is said that the problems solved using the AHP method are complex. Therefore, the input used to solve this problem is human thinking. The AHP method divides a situation into parts and organizes these parts or variables in a hierarchical arrangement. The TOPSIS method was developed based on the concept that the selected alternative should have the smallest distance from the positive ideal solution and the largest distance from the negative ideal solution. Considering that the comparison between criteria and options cannot be done definitively, fuzzy set theory is used to achieve results by the real world [24]. If the assigned value is 0, the element does not belong to the collection. If the assigned value is 1, the element completely belongs to the set. Finally, if the value lies in the interval [1], the element has a certain degree of membership (partially belongs to the fuzzy set). Then, a fuzzy set contains elements that have different degrees of membership. The main feature of fuzzy is the grouping of people into classes that do not have clear boundaries. According to Junior et al. [14], fuzzy set theory together with MCDM methods has been widely used to deal with uncertainty in the decision-making process of supplier selection, because it is a suitable language for handling imprecise criteria and integrating quantitative factor analysis. and provides quality.

The main goal of this article is to evaluate and select a supplier in an organizational resource supply chain based on a multi-criteria decision-making model using fuzzy TOPSIS. In this paper, the selected criteria were validated through a case study in which a fuzzy TOPSIS model was used to select a supplier for the detergent industry. The simple and flexible nature of this technique motivated its use in this work due to the small number of experts employed, thus ensuring fast and accurate processing of information. Through this study, it will be possible to guide the experts of the detergent industry and other industries using MCDM methods in the evaluation and selection of suppliers.

2 Theoretical foundations and research background

The concept of supply chain management (SCM) was developed in the 1980s [16]. In recent years, researchers have widely investigated the overall performance of the production chain by selecting the best possible supplier for a product or service. Suppliers are vital partners and play a strategic role in every organization, because their activities directly affect the competitive capacity and profitability of the company [13]. Therefore, the decision-making process applied to select suitable suppliers, based on their performance evaluation, is one of the most vital and fundamental tasks of the SCM field and should be based on the selection of the representative and relevant criteria.

It is essential to choose the best criteria and determine their respective weights, because it creates a basis for a fair and reliable analysis of suppliers and significantly affects the ranking of alternatives. However, it is not always possible to establish precise numerical criteria for this purpose. Therefore, linguistic variables such as "good", "average" or "poor" are often used by decision makers to express their opinions [10, 33]. Despite the formation of an organic form of judgment that respects human cognitive limitations, the use of linguistic terms is associated with a high level of uncertainty due to the subjective and imprecise inherent of the understanding of each decision maker [34]. Due to the increasing complexity of operations, traditional methods that are based only on simple evaluation of suppliers through the experience of judges or trial-and-error strategies are no longer efficient. Therefore, the use of decision models that reduce the effects of this uncertainty is more likely to obtain real results than deterministic models [31].

Supplier selection is a typical problem in multi-criteria decision-making with high complexity, which is a very useful tool for identifying the most suitable alternative, in which a limited number of suppliers are evaluated against a group of conflicting criteria [20]. MCDM models combine qualitative techniques, which are highly dependent on the opinion of decision makers and are inherently non-quantifiable, with quantitative procedures that depend on a mathematical and data-driven approach. In the last decade, different MCDM techniques have been proposed to allow consideration of multiple criteria and alternatives simultaneously. Each has its own advantages and limitations, which have been studied strongly depending on the business context. Therefore, the choice of the best method to be used is directly related to the complexity and type of the problem in question, making it impossible to define a single model that satisfies all situations [21, 8].

Among the various MCDM techniques that are used to solve the supplier selection problem, some of the most useful ones are: Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), Topsis Based on Similarity to the Ideal Solution (TOPSIS), Vicor (VIKOR), preferred ranking organizational method for enriching evaluations (PROMOTHEE), evaluation laboratory approach and decision-making test (DEMATEL), and the best-worst method (BWM). Some authors have also suggested the use of hybrid models, which are combined MCDM techniques, to reduce the weaknesses presented by them when used separately [12].

Hierarchical analysis and TOPSIS methods are among the most common and widely used multi-criteria decision-making methods. Because they are faster, more flexible, more understandable and simpler than other MCDM techniques introduced in the literature. However, despite its widespread use, traditional TOPSIS has limitations. The main case is related to the use of clear numbers that are usually not efficient in representing the subjective nature of human thinking, in real situations, it may cause it not to accurately reflect the preferences of decision makers [17]. Therefore, the traditional TOPSIS cannot manage the ambiguous information of experts' evaluations [19]. To overcome this deficiency, several studies have implemented fuzzy logic concepts along with MCDM techniques to solve problems in the field of supplier selection and what is called fuzzy multi-criteria decision making (FMCDM).

Fuzzy set theory (FST) was first proposed by Zadeh. The methodology was based on the principle that human thinking is always ambiguous when choosing an alternative among others with different levels of relevance. Since then, it has been used in combination with different methods to solve complex problems and provides the possibility of reducing the inherent uncertainties in the subjective judgment of experts. Fuzzy set theory uses linguistic variables instead of exact values and improves the communication of evaluators and increases the accuracy of the results [26]. Therefore, the fuzzy TOPSIS method (FTOPSIS) has been widely used in supplier selection problems, alone or integrated with other techniques. Various internal and external research has been conducted in this field: Boyerhosni and Kazemi [5] used three simple weighted sum methods, Mora and Topsis in research to rank suppliers. Sattari [28], in a research using two criteria, VIKOR and max-min, ranked the optimal supplier in terms of criteria and factors desired by the managers and experts of the wire and cable factory. In a research, Arabi et al. [4] used FAHP and the TOPSIS fuzzy hierarchical analysis method regarding the development of supplier selection indicators and the selection of the best supplier in a manufacturing company. In a research, Mohammadi et al. [23] used the fuzzy TOPSIS approach to select a supplier in a service and cleaning company and obtained the weights of criteria using fuzzy ANP based on pairwise comparisons. In a research, Sufi Fard et al. [30] used the multi-objective particle swarm optimization algorithm to evaluate and select suppliers in the military supply chain and order allocation. In a research, Rasmussen et al [25] used three multi-criteria decision making methods, AHP, TOPSIS and SECA, in the supplier selection process in the framework of an aerospace and defence company. Soygüder & Geçer [29] used AHP and TOPSIS fuzzy methods in a research to select the most suitable supplier. In a research, Agrawal [1] used the organizational method of preference ranking to enrich evaluations for supplier selection. Leong et al. [18] in a research using the proposed method, the importance levels of the criteria were obtained using GRA, and the weight of the criteria was calculated using BWM along with the homogeneity test, and they used TOPSIS to evaluate the suppliers' performance. Wang et al. [32] in their research used the fuzzy hierarchical analysis process to determine the weight of all potential suppliers and used the organizational method of preferential ranking to enrich the evaluations in the supplier ranking. Evcioğlu & Kabak [9] used the Hierarchical Analysis Process method and TOPSIS method for the ideal selection and ranking among alternative suppliers in a research to prioritize supplier evaluation criteria.

According to the literature review, the following objectives have been considered for the presented hypothetical case study:

1. Identifying key criteria and sub-criteria for supplier evaluation in detergent industries

2. Weighting and sub-criteria for selecting suppliers with AHP method in detergent industries

3. Selecting the best supplier using the fuzzy TOPSIS method in the detergent industry

3 Research methodology

In the current research, according to the nature of the research problem, a sequential mixed approach (qualitative-quantitative) was used. The research is descriptive in terms of method and practical in terms of purpose. The statistical population of the research are experts active in the purchase and supply of materials in the detergent industry. To select the qualitative part of the community, 10 university professors and experts, managers and experts active in the detergent industry, who had at least 10 years of experience in executive, academic and research fields, were selected through non-probability and purposeful sampling.

The selection criteria of suppliers and decision-making options in the detergent industry were identified by reviewing research and library sources, and then, using the opinions of experts, they were finalized and turned into two questionnaires. The research population in the quantitative part was 40 experts active in the purchasing and supply of materials in the detergent industry, who were selected by the available random sampling method.

To weigh and importance of decision-making criteria using the Analytical Hierarchy (AHP) method, the first questionnaire includes 28 sub-criteria and 4 main criteria. According to this questionnaire, Satty's 9-point scale was used for pairwise comparisons of sub-criteria so that the respondents could compare the criteria with better freedom of action compared to 5-point scales [2]. The respondents were asked to evaluate the importance of each scale compared to the other and to give a score between 1 and 9 to each question. A score of 1 indicates the same importance of two elements, and a score of 9 indicates a very high importance of one element in comparison with another element. To determine the final weight of the suppliers, the fuzzy TOPSIS technique was used. Considering the quality of the influential parameters and reducing the error in quantifying the qualitative parameters to small amounts, this technique was used. Therefore, the second questionnaire was designed to form a fuzzy decision matrix. The respondents were asked to compare 4 supplier groups in terms of supplier selection criteria according to 7 verbal variables [7].

3.1 Hierarchical method (AHP)

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that was first developed by Thomas L. A watch was introduced in the 1970s. This method is used in situations where decision-making is associated with complex challenges and several qualitative and quantitative criteria. Also, this method provides the ability to formulate problems hierarchically, considers different options in the decision-making process, and makes it possible to analyze the sensitivity to criteria and sub-criteria. However, creating a decision matrix requires pairwise comparisons between options, which can lead to long calculations and low accuracy [24]. The steps of implementing the AHP technique were carried out as follows:

1. Creating a decision-making hierarchy tree: The decision strategy is in graphic form. At the lowest level of this tree, the decision goal is located. The intermediate levels include criteria that influence decision-making, and the final level is dedicated to decision-making options. The selection of criteria and sub-criteria effective for the purpose of the decision at this stage is considered a key and important part. The first questionnaire was scored on a scale of 1 to 9 based on the opinion of experts to know the criteria and sub-criteria. After averaging the results, the questionnaire was given to them again, along with the average score of the previous stage, to apply the final changes to the scores according to the deviations of the first answer from the average. Then, the average scores for each criterion were calculated and the cases with a score of less than 7 were removed, and the remaining criteria and sub-criteria were presented to draw a decision-making hierarchical tree in three levels of the goal, criteria and sub-criteria as shown in Figure 1.

2. Forming the matrix of paired comparisons between nxn indices: In this step, to achieve the relative weight of each of the criteria, the matrix of paired comparisons was formed. At this stage, the experts were asked to rank the criteria and sub-criteria of the hierarchical decision-making tree in order of importance to the goal and priority to each of the criteria based on the 9-hour preference degree (1 = equal preference to 9 - extremely preferred) to compare. This matrix has a diameter of 1, the upper triangular matrix is the inverse of the lower triangular matrix.

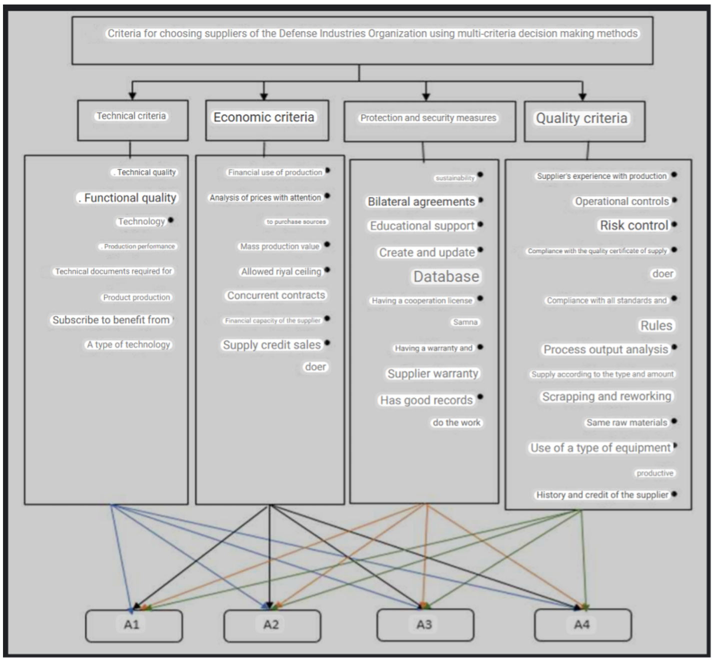

Figure 1: Hierarchical decision-making tree

To get priorities, the concept of normalization and weighted average is used. That is, different options are compared with each other based on the results obtained in terms of each criterion and then normalized by the weighted average; then the information obtained in this way is stored in a matrix whose rows and columns are options. decision-making criteria and criteria, regularly and using the concept of weighted average, the weights obtained for each of the criteria are multiplied in the previous normalized column matrices, and the results are displayed in rows with Finally, the comparison and priority of each option is determined with the rest of the options.

Consistency rate: Consistency rate is a mechanism that expresses to which the priorities obtained from the combined table can be trusted. A constant number was used to compare criteria in the matrix of pairwise comparisons.

3.2 The fuzzy TOPSIS method (FTOPSIS)

TOPSIS is an MCDM method, which is based on the principle of "relative approximation to an ideal solution". In other words, the main goal is to find an optimal solution from several options, and the ranking is done using the positive ideal solution (PIS) and the negative ideal solution (NIS). This technique is based on the concept that the chosen option should have the smallest distance from the positive ideal solution (the best possible case, A_i+) and the largest distance from the negative ideal solution (the worst possible case, A_i^-) [20]. In this technique, after defining the weight for each predetermined criterion, the scores are calculated, normalized, and then the geometric distance of each alternative is calculated for PIS and NIS. The best alternative is then selected through the proximity coefficient, which can be considered a composite classification index and indicates the alternative with the greatest similarity to the ideal solution.

In the classic TOPSIS approach, the input information that forms the decision matrix must be numerical and well-defined. Despite being an easy-to-understand method, its application in isolation is inefficient in solving supplier selection problems, because it is not able to manage uncertainty. Nevertheless, the TOPSIS method can be adapted to deal with the ambiguity of evaluation information through its integration with fuzzy logic. Fuzzy TOPSIS combines traditional TOPSIS with fuzzy set theory, where weights are defined as linguistic terms and then converted to fuzzy numbers [26]. The framework of the proposed MCDM supplier selection model is presented in Figure 2.

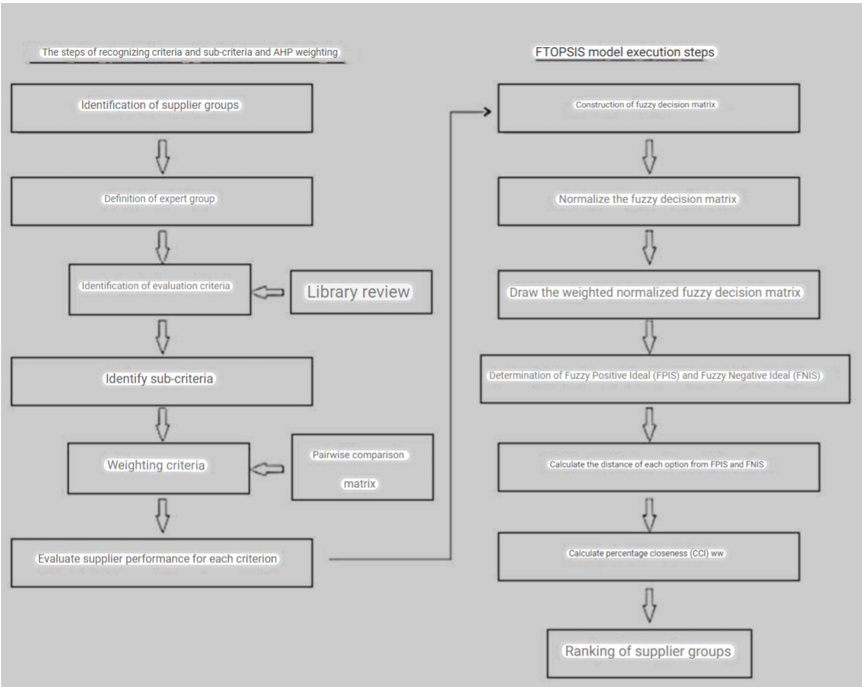

Figure 2: The framework of the proposed MCDM supplier selection model

After assigning weights to criteria using linguistic variables and generating decision matrices consisting of fuzzy numbers defined in the interval $(0, 1)$, fuzzy TOPSIS is formulated in the following steps:

The first step: the decision matrix (D) is normalized (unscaled):

$$r_{ij} = r_{ij} / \sqrt{\left(\sum_{(j=1)}^{i} r_{ij}^2\right)} \quad j = 1, 2, 3 \ldots n \quad i = 1, 2, 3 \ldots m.$$

The obtained matrix is called N_D.

The second step: the normalized weights of the decision matrix are obtained as follows:

$$V = N_D^\star W_(n^\star n) \quad j = 1, 2, 3 \ldots n \qquad i = 1, 2, 3 \ldots m,$$

where V is the weighted scaleless matrix and W is a diagonal matrix of the obtained weights for the indicators.

The third step: the positive ideal solution (A_i^+) and the negative ideal solution (A_i^-) are defined as follows:

$$A^+ = \{(MAX_i V_{ij} \mid ij \in J_1)\ ,\ (MIN_i V_{ij} \mid ij \in J_2)\ \mid i = 1, 2, 3, \ldots, m\} \text{ positive ideal option}$$

$$\text{Negative ideal option} = A^- = \{(MIN_i V_{ij} \mid ij \in J_1)\ ,\ (MAX_i V_{ij} \mid ij \in J_2)\ \mid i = 1, 2, 3, \ldots, m\}$$

$$A_i^+ = \{v_1^+, v_2^+, \ldots, v_n^+\}$$

$$A_i^- = \{v_1^-, v_2^-, \ldots, v_n^-\}$$

so that for the positive elements of indexes $J_1 = \{1, 2, 3, \ldots, n_I\}$.

Fourth step: we get the distance size based on the Euclidean formula for the negative ideal solution and the positive option and the same size for the positive ideal solution and the negative option as follows:

$$d_i^+ = \sqrt{\left(\sum_{(j=1)}^{n} (v_{ij} - v_j^+)\right)} \quad i = 1, 2, 3, \ldots, m$$

$$d_i^- = \sqrt{\left(\sum_{(j=1)}^{n} (v_{ij} - v_j^-)\right)} \quad i = 1, 2, 3, \ldots, m.$$

Fifth step: The relative proximity of A_i to the ideal solution is calculated as follows:

$$C_i = (d_i^-)/(d_i^+ + d_i^-), \quad (i = 1, 2, 3, \ldots, m).$$

If $A_i^+ = A_i$, then $d_i^+ = 0$ and $C_i = 1$, and if $A_i^- = A_i$, then $d_i- = 0$ and $C_i = 0$, so each option A_i is an idea solution A_i is closer, its C_i value will be closer to one.

Sixth step: according to the obtained comparison of Ci for each option based on non-fuzzy values, the order of ranks is obtained. After obtaining the entry ranks, the following mathematical steps are performed [11]:

Step 1: Forming a decision matrix in the order of m×n with suppliers' inputs. where there are a number of alternative suppliers and the number of evaluation criteria.

Step 2: Normalization of the decision matrix by dividing each individual value in each column by the maximum value of the same column, where all three elements of the normalization value are considered equal to their upper level.

Step 3: According to the priority of importance of the criteria, different weights are suggested or defined by the decision maker. The weights are converted into fuzzy values. Those fuzzy values of weights are normalized by dividing each value by the sum of weights and become a normalized matrix.

Step 4: Construction of the weighted normalized decision matrix is done by multiplying the normalized decision matrix by its corresponding weights.

Step 5: This step is to determine the positive ideal solution and the negative ideal solution. All evaluation criteria were converted into profit criteria. Sabzi and King [35] used $(1, 1, 1)$ as positive ideal solution and $(0, 0, 0)$ as negative ideal solution in this environment.

Step 6: This step is dephasing. The separation of each alternative from the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS) was determined.

Step 7: Relative proximity to the ideal solution is calculated. This value is used to rank each individual option. Relative proximity indicates the relative distance of each alternative from the non-ideal point. It is obvious that the highest value of the proximity coefficient indicates the most preferable solution that has the greatest distance from the non-ideal point.

Step 8: The larger the value of $C_i^\star$, the better the performance of the alternatives. According to this concept, then the options are ranked to choose the optimal option.

The mathematical equations used were operationalized through computational simulation in MATLAB.

4 Research findings

4.1 Selection of supplier evaluation criteria and sub-criteria from experts' point of view and decision making hierarchy tree drawing

According to the opinion of experts active in the purchasing and supply of materials in the detergent industry, four groups of suppliers (A1, A2, A3 and A4) were identified as options in this research. In this stage, a list of criteria and sub-criteria for evaluation and selection of suppliers was identified and scored based on library research and experts' opinions. Based on scoring results and average scores, 4 criteria (quality, protection and security, economic and technical) and 28 sub-criteria were approved. The goal (selection of suppliers) was placed in the first level, criteria for selecting suppliers in the second level, sub-criteria in the third level, and finally, 4 supplier nodes (options) were placed in the last line. The hierarchical structure of decision-making is presented in Figure 1.

4.2 Determining the weights of criteria and sub-criteria based on the AHP method

The matrix of pairwise comparisons of criteria is presented in Table 1. According to the opinion of detergent industry experts, quality factors with a weight of 0.367 are the most important and economic criteria with a weight of 0.218 are the least important.

Table 1: Matrix of pairwise comparisons and relative weights of criteria

Criteria	Quality	Safety and Security	Economic	Technical	Weight
(C1)	(1, 1, 1)	(1.13, 1.53, 1.87)	(0.64, 0.87, 1.18)	(1.76,2.10, 2.62)	0.367
(C2)	(0.75, 0.98, 1.42)	(1, 1, 1)	(0.73, 0.94, 1.34)	(1.22,1.45, 1.97)	0.304
(C3)	(1.42, 1.95, 2.29)	(1.01, 1.28, 1.42)	(1, 1, 1)	(0.97,1.09, 1.23)	0.218
(C4)	(1.18, 1.53, 1.98)	(0.86, 1.03, 1.37)	(0.89, 1.34, 1.85)	(1, 1, 1)	0.276

For each of the sub-criteria, a matrix of paired comparisons was formed, and the weight of the sub-criteria was determined. A pairwise comparison of options was done for each criterion and sub-criterion, and the relative weight was calculated in MATLAB software. The consistency coefficient of all criteria was less than 1, so the consistency of the model criteria is confirmed. To calculate the final weight of the options, the relative weight matrix of the options must be multiplied by the weight matrix of the sub-criteria. The results of calculating the final weight of the sub-criteria are presented in Table 2.

4.3 Evaluation of suppliers in each criterion with the fuzzy TOPSIS technique

After determining the weight of each of the criteria and sub-criteria in the AHP method, the performance of each of the supplier groups (A1, A2, A3 and A4) was evaluated by the fuzzy TOPSIS method. For this purpose, experts were polled verbally about all 28 criteria. All criteria are positive. According to the fuzzy spectrum corresponding to each of the verbal expressions, the fuzzy decision matrix is in the form of Table 3.

Using the survey data from experts and the averaging method, the decision-making matrix was obtained in the form of table 4.

In the next stage of normalization or de-scaling of the matrix to convert the criteria into a single scale for comparison, linear scale transformation was used and the normal decision-making matrix was obtained in the form of Table 5.

The fuzzy decision-making matrix is parametric and must be quantified. For this purpose, the decision-maker determines the weight for each criterion; The set of weights is multiplied by the normalized matrix. Using the weights of the hierarchical AHP method (Table 2) and the values of the normal decision-making matrix (Table 5), the weighted decision-making matrix was calculated. For this purpose, it has been calculated using the formula $V_{ij} = r_{ij} \cdot w_{ij}$. The results are presented in Table 6.

In the next step, the solution of positive ideals and negative ideals was calculated. The results are presented in Table 7. The two virtual options created are actually the worst and the best solutions.

Then the distance between each option was calculated using the Euclidean method. That is, the distance of the options from the positive and negative ideal options was determined, and the supplier groups were prioritized based on this coefficient.

Table 2: Final weight of sub-criteria

Criterion	Criterion Weight	Sub-criteria Sub-criteria	Sub-criteria Weight	Final Weight
Technical	0.276	Technical Quality	0.3895	0.107
		Functional Quality	0.2956	0.081
		Technology	0.1127	0.031
		Production Performance	0.0734	0.020
		Technical Master Required for Product Manufacturing	0.0803	0.022
		Shared Use of a Type of Technology	0.0485	0.013
Quality	0.367	Supplier's Experience with Production	0.0740	0.027
		Operational Controls	0.1680	0.061
		Risk Control	0.0443	0.016
		Compliance with Supplier Quality Certificate	0.1319	0.048
		Adherence to All Standards and Regulations	0.1030	0.037
		Analysis of Supply Process Outputs Based on Scrap, Waste, and Rework	0.1080	0.039
		Uniform Raw Materials	0.0448	0.016
		Use of One Type of Production Equipment	0.0312	0.011
		Supplier's Track Record	0.2100	0.077
		Supplier's Reputation	0.0846	0.031
Economic	0.218	Financial Use of Production	0.2275	0.049
		Price Analysis Based on Purchase Resources	0.1138	0.024
		Value of Mass Production	0.3399	0.074
		Authorized Monetary Limit for Concurrent Contracts	0.1507	0.033
		Supplier's Financial Capability	0.1867	0.040
		Supplier's Credit Sales	0.0952	0.020
Safety-Security	0.304	Stability	0.2100	0.063
		Bilateral Agreements	0.1602	0.048
		Educational Support	0.1080	0.032
		Creation and Updating of Information Database	0.1219	0.037
		Having SEMA Cooperation License	0.0846	0.025
		Supplier's Warranty and Guarantee	0.1020	0.031
		Good Performance Records	0.0446	0.013

Table 3: Verbal spectrum expressions and fuzzy values

Spectrum	Verbal Expressions	Low (L)	Medium (M)	High (U)
1	Very Poor	1	1	3
2	Poor	1	3	5
3	Medium	3	5	7
4	Good	5	7	9
5	Very Good	7	9	11

Table 4: Fuzzy decision matrix

Supplier Group - Quality and Safety-Security

Supplier Group	Quality (L)	Quality (M)	Quality (U)	Safety-Security (L)	Safety-Security (M)	Safety-Security (U)
A1	1.538462	3.461538	5.461538	1.384615	3.076923	5
A2	1.923077	3.769231	5.769231	1.538462	3.461538	5.461538
A3	2.000000	3.923077	5.923077	1.307692	3.153846	5.153846
A4	1.538462	3.307692	5.307692	1.692308	3.461538	5.461538

Supplier Group - Economic and Technical

Supplier Group	Quality (L)	Quality (M)	Quality (U)	Safety-Security (L)	Safety-Security (M)	Safety-Security (U)
A1	1.384615	3.000000	5.000000	1.692308	3.384615	5.307692
A2	1.769231	3.615385	5.615385	1.769231	3.538462	5.461538
A3	1.538462	3.307692	5.307692	1.461538	3.153846	5.000000
A4	1.692308	3.461538	5.461538	1.461538	3.230769	5.153846

Table 5: Normal fuzzy decision matrix

Supplier - Quality and Safety-Security

Supplier Group	Quality (L)	Quality (M)	Quality (U)	Safety-Security (L)	Safety-Security (M)	Safety-Security (U)
A1	0.2597	0.5844	0.9221	0.2535	0.5634	0.9155
A2	0.3247	0.6364	0.9740	0.2817	0.6338	1.0000
A3	0.3377	0.6623	1.0000	0.2394	0.5775	0.9437
A4	0.2597	0.5584	0.8961	0.3099	0.6338	1.0000

Supplier - Economic and Technical

Supplier Group	Quality (L)	Quality (M)	Quality (U)	Safety-Security (L)	Safety-Security (M)	Safety-Security (U)
A1	0.2466	0.5342	0.8904	0.3099	0.6197	0.9718
A2	0.3151	0.6438	1.0000	0.3239	0.6479	1.0000
A3	0.2740	0.5890	0.9452	0.2676	0.5775	0.9155
A4	0.3014	0.6164	0.9726	0.2676	0.5915	0.9437

Table 6: Weighted decision matrix

Supplier - Quality and Safety-Security

Supplier Group	Quality (L)	Quality (M)	Quality (U)	Safety-Security (L)	Safety-Security (M)	Safety-Security (U)
A1	0.1013	0.2279	0.3596	0.1014	0.2254	0.3662
A2	0.1266	0.2482	0.3799	0.1127	0.2535	0.4000
A3	0.1317	0.2583	0.3900	0.0958	0.2310	0.3775
A4	0.1013	0.2178	0.3495	0.1239	0.2535	0.4000

Supplier - Economic and Technical

Supplier Group	Quality (L)	Quality (M)	Quality (U)	Safety-Security (L)	Safety-Security (M)	Safety-Security (U)
A1	0.0567	0.1229	0.2048	0.1208	0.2417	0.3790
A2	0.0725	0.1481	0.2300	0.1263	0.2527	0.3900
A3	0.0630	0.1355	0.2174	0.1044	0.2252	0.3570
A4	0.0693	0.1418	0.2237	0.1044	0.2307	0.3680

Table 7: Positive ideal and negative ideal solution matrix

Solution - Quality and Safety-Security

Supplier Group	Quality (L)	Quality (M)	Quality (U)	Safety-Security (L)	Safety-Security (M)	Safety-Security (U)
Positive Ideal	0.39	0.39	0.39	0.40	0.40	0.40
Negative Ideal	0.0658	0.0658	0.0658	0.0732	0.0732	0.0732

Solution - Economic and Technical

Supplier Group	Quality (L)	Quality (M)	Quality (U)	Safety-Security (L)	Safety-Security (M)	Safety-Security (U)
Positive Ideal	0.23	0.23	0.23	0.39	0.39	0.39
Negative Ideal	0.0504	0.0504	0.0504	0.0879	0.0879	0.0879

Table 8: Distance to the positive ideal solution

Supplier	Quality	Safety-Security	Economic	Technical	$S + S^{+} + S$
A1	0.192	0.2007	0.1185	0.1775	0.9862
A2	0.1728	0.1862	0.1025	0.1716	0.9248
A3	0.1674	0.2014	0.111	0.1913	0.9875
A4	0.1955	0.1804	0.1059	0.1892	0.9308

Table 9: Distance to Negative Ideal Solution

Supplier	Quality	Safety-Security	Economic	Technical	$S - S^{-} - S$
A1	0.1948	0.1913	0.0985	0.191	0.954
A2	0.2126	0.2167	0.1187	0.1999	1.0396
A3	0.2209	0.1983	0.1084	0.1747	0.9666
A4	0.1869	0.2174	0.1136	0.1818	1.0211

The distance size (closeness coefficient, Cci) to the positive and negative ideal solution was determined. The closeness to the positive and negative ideal solution was calculated, and then the supplier groups (options) were ranked (Table 10). The results indicate that supplier group A2 has the highest priority, followed by supplier groups A4, A3, and A1, respectively.

Table 10: Results of Closeness to Positive and Negative Ideal Solution and Supplier Ranking

Supplier	$S + S^{+} + S$	$S - S^{-} - S$	CciCciCci	Rank
A1	0.9862	0.954	0.4917	4
A2	0.9248	1.0396	0.5292	1
A3	0.9875	0.9666	0.4946	3
A4	0.9308	1.0211	0.5231	2

5 Discussion and conclusion

Real-world decision-making issues are typically very complex and unstructured, which can be considered through examining a criterion or perspective leading to optimal decision-making. Competition in price and quality is no longer just about effectively managing facilities and production; moreover, the optimal use of scarce resources and finding ideal and cost-effective suppliers for raw materials and production have become important topics in supply chain management. The crucial point is managing these suppliers based on efficiency. Optimal supplier selection today combines new perspectives to better allocate resources, minimize risks associated with procurement, and reduce costs by saving time, money, and expenses. Traditional supplier selection methods have often been qualitative and judgment-based, while quantitative research helps in modelling, data analysis, and producing clear results. Considering all these requirements, choosing the right supplier is one of the most important processes for success in supply chain management and staying ahead of competitors.

This paper implements AHP and fuzzy TOPSIS models to select the most suitable supplier, and implementation through a case study demonstrates the feasibility of the proposed model. According to experts and industry professionals, quality factors hold the highest importance, followed by safety-security, technical, and economic criteria. Evaluation of the performance of each supplier group (A1, A2, A3, and A4) using the fuzzy TOPSIS method showed that supplier group A2 has the highest priority, followed by supplier groups A4, A3, and A1, respectively.

The results of this research do not fundamentally differ from other studies in this field. It can be concluded that using the fuzzy TOPSIS model for supplier selection issues, especially in the final stage, is appropriate. However, while the proposed model provides important criteria for supplier selection processes in the detergent industry, decision-makers can modify the number of criteria to better suit the specific needs and situations of their organization.

In general, providing a flexible and cost-effective tool for supplier selection enables procurement managers to make quick decisions. The results of this research can help decision-makers in identifying, adapting, and applying appropriate methods for supplier selection in various industries. Given the organization's policy to move towards organizing and effectively and efficiently utilizing the collaborative supply chain network, it is also necessary to comprehensively and systematically address the issue of managing the quality of supplied items.

6 Suggestions

- It is recommended that the results of this research and similar studies be utilized for more intelligent supplier selection in organizations.

- Organizations should use the identified criteria and sub-criteria in this research as supplier selection criteria to achieve more desirable selection results.
- Organizations should develop software using AHP and fuzzy TOPSIS methods with security considerations in mind to support decision-makers and evaluate ideal suppliers according to different business types.

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