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ORIGINAL ARTICLE

Supplier selection problem in global supply chains by AHP and ANP approaches under fuzzy environment

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Abstract In this paper, we proposed a model for selecting of the global supplier by analytical hierarchy process (AHP) and analytical network process (ANP) based on linguistic variable weight. The fuzzy AHP and fuzzy ANP methods are suggested to be a good tool for solving our proposed multiple-criteria decision-making problem. Fuzzy AHP-based methodology evaluated different decision criteria such as service quality, cost, risk factors, and supplier's characteristics involved in the selection of the best supplier in a global supply chain and ANP represented an effective tool for providing a suitable solution for managers. The linguistic levels of comparisons produced by the experts with triangular fuzzy numbers for constructing fuzzy pairwise comparison matrices. The implementation of the system was demonstrated by a problem having four stages of hierarchy which contains four criteria and 28 attributes. In conclusion, the fuzzy AHP and fuzzy ANP results were compared.

Keywords Supplier selection · Global supply chains · Fuzzy logic · Fuzzy AHP · Fuzzy ANP

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1 Introduction

The companies have to work with different suppliers to continue their activities. In a competitive environment, to work with a right supplier is a very important problem in supply chain systems. The supply chain concept is based on the formation of a value-chain network consisting of individual functional entities committed to providing resources and information to achieve the objectives of efficient management of suppliers as well as the flow of parts [1].

The success of a supply chain is highly dependent on selection of good suppliers [2]. That is why the supplier selection is a very important and multi-criteria problem. Several factors may affect the selection decision of the managers. In this respect, supplier selection problem includes tangible and intangible factors.

Our research context focuses on global supply chains and supplier selection problems. We analyzed the global suppliers with the fuzzy AHP and fuzzy ANP methodologies for our sample company in a textile industry. After the calculations, we compared the results of both methods.

Since 1977, Saaty [3] proposed analytic hierarchy process as a decision aid to help solve unstructured problems in economics, social, and management sciences. The AHP enables the decision-makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria [4]. On the other hand, analytical network process is an extension of analytical hierarchy process.

In literature, there are lots of researches about AHP and ANP. Some of the researches are about crisp environment and the others are about fuzzy environment. Whitaker [5] used AHP/ANP for validation examples. Ismayilova et al.

[6] weighted the differences by the same methods. Chang et al. [7] evaluated digital video recorder by using AHP/ANP and also Saaty [8] made a decision with the same methods. Wong et al. [9] evaluated the system intelligence and Yüksel and Dağdeviren [10] made SWOT analysis with AHP/ANP. Wijnmalen [11] analyzed benefits, opportunities, costs, and risks with the AHP/ANP. Yu and Tzeng [12] used AHP/ANP in fuzzy environment for a decision-making problem with the defense and feedback effects. Dağdeviren et al. [13] identified faulty behavior risk in work system by fuzzy AHP/ANP [5–13].

Supplier evaluation and selection has received considerable attention in the literature. Sanayei et al. [14] used group decision-making process for supplier selection with VIKOR under fuzzy environment, Amid et al. [15] proposed weighted max–min model for fuzzy multi-objective supplier selection problem, Lee [16] proposed a fuzzy supplier selection model with the consideration of benefits, opportunities, costs, and risks, Chang et al. [17] used fuzzy DEMATEL method for developing supplier selection criteria, Tsai et al. [18] proposed a dynamic decision approach for supplier selection using ant colony system, Amin et al. [19] used fuzzy SWOT analysis and fuzzy linear programming for supplier selection and order allocation, Lin et al. [20] proposed an ERP model for supplier selection, and Liao and Kao [21] used Taguchi loss function, analytical hierarchy process, and multi-choice goal programming for a supplier selection problem [14–21].

Since we used the AHP and ANP methodologies under fuzzy environment, we only focused on the supplier selection literature related to these methods and similar approaches. Some examples of the supplier selection literature related to AHP and ANP are given as follows. Chamodrakas et al. [22] used satisficing and fuzzy AHP for a supplier selection problem in electronic marketplaces, Ghodsypour and O'Brien [23] proposed an integration of an AHP and linear programming to consider both tangible and intangible factors in choosing the best suppliers, Kokangül and Susuz [24] used integrated analytical hierarch process and mathematical programming to supplier selection problem with quantity discount, Chan and Kumar [25] presented a fuzzy extended AHP-based methodology for global supplier selection, Hsu and Hu [26] applied hazardous substance management to supplier selection using analytic network process, and Vinodh et al. [27] used fuzzy analytic network process for supplier selection in a manufacturing organization. Although there were a number of publications selecting the most suitable supplier alternatives in the literature and some of them have been prepared using the multi-attribute/multi-criteria decision-making methods considering human judgments, tangible, intangible, and multiple criteria, there is no evidence in the literature that any of them were prepared with the aim of the selection of the suitable supplier using AHP and ANP methodology under a fuzzy environment and their comparisons [22–27].

In our model for selecting the best supplier in a global supply chain in a textile industry, we used analytical hierarchy process method based on the linguistic variable weight method to overcome some of the shortcomings of the method, and we widened our analysis with analytical network process method based on linguistic variable weight method, too.

Our study proposes an AHP and ANP methodology for evaluating and selecting the most suitable suppliers for a textile company as a real-world application under a fuzzy environment. Fuzzy AHP and fuzzy ANP are used to select a supplier alternative and they are applied to calculate criteria weights. In both methodologies, decision makers' linguistic evaluations in fuzzy forms are used to performed pairwise comparisons. In these methodologies, we use triangular fuzzy numbers in all pairwise comparison matrices. Hence, criteria weights are calculated as the triangular fuzzy numbers and then these fuzzy criteria weights are inserted to the fuzzy AHP and ANP methodologies to rank the alternatives.

The rest of the paper is organized as follows. Section 2 describes supply chain management and global supply chains. Section 3 identifies the selection criteria for a supplier selection problem. Section 4, fuzzy theory is briefly reviewed and the basics of the fuzzy AHP and fuzzy ANP described, respectively. Sections 5.1 and 5.2 present application of the integrated model to the supplier selection problem as a real-world case with fuzzy AHP and fuzzy ANP, respectively. The results of the application are discussed and main findings and contributions are drawn and future developments are suggested in Section 6.

2 Supply chain management and global supply chains

The supply chain is an integrated business model for logistics management. It covers the flow of goods from suppliers through manufacturing and distribution chains to the end consumer [28]. Supply chain management is an increasingly applied operations paradigm for enhancing overall organizational competitiveness [29].

The concept of logistics outsourcing has generated considerable interest in organizations worldwide during the past several years and logistics outsourcing represents an organization's decision to enter into a contract that allows an external supplier to perform all or part of the company's logistic functions [30]. Logistics outsourcing involves the use of external companies to perform logistics functions that have traditionally been performed within an organization and a key rationale for this form of outsourcing is that with intensified global competition, firms are

concentrating their energies on core activities that are critical to survival and leaving the rest to specialized firms [31].

Supply chain management is a holistic and a strategic approach to demand, operations, procurement, and logistics process management [32]. In literature, there are lots of definitions of the supply chains and the objective of the supply chain management. In general, a supply chain is defined as "a process that transforms materials into products and delivers them to customers through specific activities," and the objective of the supply chain management is to improve the efficiency of the product delivery process by delivering the right product at the right time to the end customers by the suppliers while keeping the handling and storage cost low [33]. Furthermore, supply chain management incorporates the entire exchange of information and movement of goods between suppliers and end customers, including manufacturers, distributors, retailers, and any other enterprises within the extended supply chain [34].

Companies and manufacturers are now seriously exploring the potential of the concept of supply chain management to improve their revenue growth. Because the companies know, with the supply chain management, supply chain risk and uncertainty can be reduced. This improvement gives a chance to supplying high-level customer service, customer satisfaction, and profitability. In light of the most of researches, it is clear that an effective supply chain management is an essential strategy for success in the both local and global markets.

In today's rapidly changing world, supply chain management becomes global supply chain management with the international transportation possibilities. The manufacturers look for the best supplier for their global transportation activities. Because they know that they have to attempt the global supply chain management activities to develop agile supply chains to get their product to market faster at a minimum total cost in a global environment. In Fig. 1, the elements of the global supply chain management are represented.

With the global transportation, the manufacturers have to configure their production and distribution systems and strategies to provide the desired customer service at the lowest possible cost while maximizing their after tax profit [35]. The maximization of the profit is as important as for all sectors and activities in a global supply chain management concept.

Under conditions of global competition, forces oriented either upstream from global supply resources or downstream from global markets have made numerous international manufacturing enterprises perceive the urgent necessity of developing competitive global logistic modes [36].

A global supply chain is a network of supply chain facilities and material sourcing on a worldwide basis and is concerned with the flow of information, material, and funds through different stages across countries [37]. For many global supply chain networks that can comprise hundreds of companies with over several tiers of suppliers and intermediate customers, there are numerous presenting risks to consider and tackle [38]. That is why the selection process of the supplier is very important in a global supply chain. With the incapable suppliers, lower job commitment and greater job dissatisfaction are shown in supply chain management systems.

Successful execution of coordinated marketing strategies in global supply chains will depend partially on free flowing information on such sensitive data as customer satisfaction levels, customer complaint data, new product ideation and development, account management plans, marketing communication plans, and planned operational changes [39]. Furthermore, for being successful and having no problem for the companies, they have to consider that the suppliers' production capacity and quality levels are more at risk. Because risk factors seriously threatens the global supply chain's performance.

Supplier selection decisions change the global supply chain design problem in fundamental ways, in part because they are based on more broadly defined criteria and suppliers are typically selected based on the buyer's perception of the supplier's ability to meet quality, quantity, delivery, price, and service needs of the company [40].

3 Selection criteria for a supplier selection problem

The problem has a hierarchy with four levels, and the different decision criteria, attributes. The decision alternatives will be further discussed. In the hierarchy, the overall objective is placed at level 1, criteria at level 2, attributes at level 3, and the decision alternatives at level 4.

The main objective here is the selection of the best supplier in a global supply chain for our sample company in textile industry. Our company is in Istanbul, and it is committed to offering real value for money for fashion and up-to-date casual and jeans wear. The company exports their product from Turkey to Russia, Cyprus, Ukraine, Albania, and Azerbaijan, and it works with global suppliers for supply needs. The hierarchy of the selection criteria, attributes, and decision alternatives can be seen in Fig. 1. The criteria and attributes identified and analyzed in this paper can be seen in previous researches in literature.

3.1 Service quality (C_1)

The high level of service quality is a source for competitive advantage. With the service quality, there are differences among the supplier alternatives. The quality of the products affects the customers' impression. That is why, the high

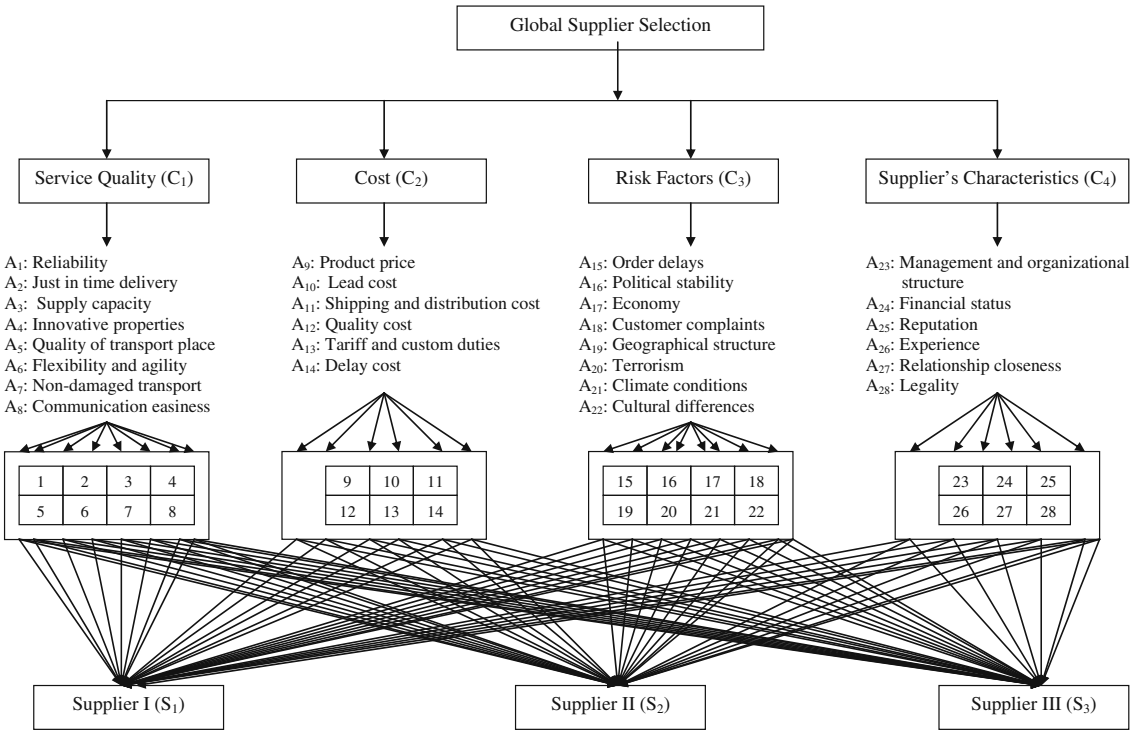

Fig. 1 The hierarchy of the supplier selection problem

quality of the products are very important in a global supply chain. The performance of the supplier in providing service to the manufacturer also affects the service quality performance. The high service quality given by the supplier may help increasing the customer satisfaction and customer loyalty. The factors affecting service quality criteria can be stated as follows:

Reliability (A_1) The suppliers have to keep their words about the transportation condition such as transport place, transport time, transportation capacity, and all the cost about transportation, their managerial structure, communication features, technological conditions, and the others. The managers can tend to choose the suppliers with their attributes about reliability.

Just in time delivery (A_2) The suppliers have to follow the predefined delivery schedule for achieving on-time delivery. All the manufacturers want to work with the supplier who can manage the supply chain system on time and has the ability for following the exact delivering schedule table.

Supply capacity (A_3) The transportation capacity is very important for evaluating of the supplier alternatives. It depends on transportation vehicles and different warehouses capacities. Probably the companies go towards to select the supplier with more capacity.

Innovative properties (A_4) Technology is changed with an unbelievable speed. To being the best in today's competitive world, the companies have to have innovative properties in their management activities. The transportation innovations and research-development studies have to be supported by the supplier companies.

Quality of transport place (A_5) This attribute is very important for the managers. The quality of the transport place affects the product directly. Poor in quality places can cause the damaged products. That is why the supplier who has a transport place with a high quality has a priority than its rivals.

Flexibility and agility (A_6) In today's business world, everything changes rapidly. The customers' demand, order frequencies, and business structures can also be changed with a high speed. More flexible suppliers can be chosen by the company managers, because managers want to manage the urgent and uncertain demands successfully. That is why the flexibility and agility characteristics are very important for evaluating the supplier alternatives.

Non-damaged transport (A_7) The companies which outsource their logistic activities have to transport own products correctly. The damaged transport products can increase the rejection rate of the product. With the increased

rejection rate of the product, the profitability of the company can decrease.

Communication easiness (A_8) Communication easiness system contains communication, commitment, and trust. The relationships between suppliers and managers can be affected by ease of communication in a long-term work life. The languages, ethics, and customs demonstrate differences from country to country. For having good relationships, the suppliers have to provide easier and more successful communication systems and ways than their rivals. They have to work their customers' special features.

3.2 Cost (C_2)

Every time, in every country, and for every sector, cost is very important. Especially in global supply chains, cost is one of the most important criteria which affect the supplier selection problem directly. Every company wants to work with the supplier who can serve the transportation activities with high quality and low cost, because as all of us know, the condition for the profit maximization can be achieved with the cost minimization. The factors which affect the cost can be stated as follows:

Product price (A_9) Having the minimum price of the product is very important for all companies' profitability. The company managers have to find the low-cost suppliers for their companies' logistic activities. The manufacturing cost, maintenance cost, and the other cost about the manufacturing process constitute the total product price.

Lead cost (A_{10}) In global sourcing, the lead cost is as important as the product price. The distribution channel length and the other transportation type style characteristics form the lead cost. Lead cost can be affected by lead time of the products. The defective parts, which are not detected in quality control process but noticed during production, can increase the lead time of the production [25].

Shipping and distribution cost (A_{11}) In global supply chain, the supplier alternatives can be analyzed by shipping and transportation cost. These costs are usually high in context with international suppliers, because of the inventory cost, damages cost in the transportation time, and insurance cost.

Quality cost (A_{12}) Having the high transportation cost is important. Wishing for being more profitable does not tolerate the high cost on transportation. Non-damaged products depend on transportation. The number of non-damaged products and high-quality product manufacturing affect quality cost directly.

Tariff and custom duties (A_{13}) The different countries have different tariff and custom duties. When analyzing the suppliers, this attribute is important in global supply chains with company managers desires about working with the best supplier with less duty and taxes.

Delay cost (A_{14}) After the transport plans, some of the transportation orders can be delayed. This order delays are reflected to the company as an order delay cost. All the companies have to work eliminating this cost for achieving profit maximization.

3.3 Risk factors (C_3)

The global supplier selection decision is most strongly affected by the risks. This selection process is more complicated and riskier than domestic supplier selection process. The risk factors criteria have the following attributes:

Order delays (A_{15}) The order delays are the risk for all companies which outsource their logistics and transportation activities. The weather conditions, overloaded transport vehicles, and some other factors are the reasons of order delays.

Political stability (A_{16}) The supplier's country's economic situation is very important. The political stability of the supplier may affect relationships between supplier and manufacturer. The manufacturer prefers to work with a supplier who has a political stability in his country. Due to the changing of the political leadership or government structure, the relationships between manufacturer and supplier can be affected badly.

Economy (A_{17}) The supplier's country's economic situation is as important as its political status because the economic status affects the country's currency exchange rate and estimating a price for products and transportation activities. In global supply chain systems, managers have to take economic situation into account before deciding which supplier they will work with.

Customer complaints (A_{18}) Customer satisfaction is the key factor of the success for all companies in all sectors. All customers want to have their needs on time, with low price, with high quality, etc. If they cannot have their needs with their expectations, they start to complain about the company. That is why the managers have to evaluate their supplier alternatives about the customer complaints.

Geographical structure (A_{19}) The supplier's mother country's geographical structure may affect the relationships

between manufacturer and supplier. When the manufacturer chooses his global supplier, he has to take the supplier's location plant, geographical conditions, and natural activities into account.

Terrorism (A_{20}) This factor firstly was introduced for a global supplier selection problem by Chan and Kumar [25]. The probability of the terrorism activities is very important for both manufacturer and supplier. The terror activities can be occurred in supplier's country, in manufacturer's country, or the country which the products are transported to. Furthermore, the terror activities can be occurred in transportation ways such as in a plane, in highways, in railways, or in seaways.

Climate conditions (A_{21}) The products can be affected by the climate conditions. The supplier's mother country's climate and the country which the manufacturer wants to transport his products to can affect the products. The suppliers who are selected by the manufacturers have to be flexible for changeable climate conditions for products' transportation quality.

Cultural differences (A_{22}) In a global supplier selection process, understanding each other is a key factor for both manufacturer and supplier. The same idea structure and the similar cultural structure can help them to communicate with each other easily and also have good relationships.

3.4 Supplier's characteristics (c_4)

The history of the supplier and supplier's characteristics are very important for selecting of the best supplier. Companies want to work with high-value suppliers. They can decide that which supplier work with by the performance and past history of the alternatives. Some of the important characteristics of suppliers are summarized below:

Management and organizational structure (A_{23}) The manufacturers want to work with a supplier which has a stable and correct management and organizational structure. The organizational structure of the supplier affects the supplier's relations with manufacturer. The manufacturers do not prefer to work with a supplier who has a problem with his organizational structure. The problematic managerial structure can discombobulate all relations.

Financial status (A_{24}) The financial stability is as important as economic structure and stability of the supplier's country. In a global supplier selection process, manufacturers have to take the suppliers financial status into account. They can analyze the supplier's financial status with annual earnings and lost reports.

Reputation (A_{25}) The reputation of the companies can be occurred with customers' satisfactions and dissatisfactions. All manufacturers want to work with a supplier who has a good reputation. With their advertisement based on customers' opinions, suppliers can find customer for transporting his products.

Experience (A_{26}) The history of the supplier probably may affect his future performance. In the selection process of the supplier, manufacturer has to analyze supplier's experiences such as business references, response to market, and on-time delivering.

Relationship closeness (A_{27}) Suppliers with a good customer-based structure should be preferred than the other alternatives. These suppliers with this ability can satisfy their customers. Response to changes, being flexible, taking care with the manufacturer's needs and expectations, and adopting the new situations rapidly are important factors for a closer relationship between manufacturer and supplier.

Legality (A_{28}) In a global environment, legality is very important in all sectors. In transportation activities, manufacturers have to examine the suppliers' legality licenses, transportation permissions for changing country transport, and overseas transportation.

4 The method of fuzzy AHP and fuzzy ANP

Chang [41, 42] developed a fuzzy extent analysis for AHP, which has similar steps as that of Saaty's crisp AHP [43]. In this paper, we used Chang's fuzzy extent analysis.

In the following, first, the outlines of the extent analysis method on fuzzy AHP are given and then in the other section, the method is applied to a supplier selection problem.

NOTATION	DESCRIPTION
$X = \{x_1, x_2, ..., x_n\}$	Object set
$U = \{u_1, u_2, ..., u_m\}$	Goal set
$M_{g_i}^j \ (j = 1, 2, ...m)$	Triangular fuzzy number
M	Extent analysis values for each object
S_i	Value of fuzzy synthetic extent with respect to the ith object
V	Degree of possibility
D	The ordinate of the highest intersection point D
W'	The weight vector
N	Number of elements
W	Normalized weight vector

Let $X = \{x_1, x_2, ..., x_n\}$ be an object set, and $U = \{u_1, u_2, ..., u_m\}$ be a goal set. According to the method of

Chang's [25] extent analysis, each object is taken and extent analysis for each goal is performed, respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{g_i}^1, M_{g_i}^2, ..., M_{g_i}^m \qquad i = 1, 2, ..., n \tag{1}$$

where all the $M_{g_i}^j (j = 1, 2, ...m)$ are triangular fuzzy numbers.The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \tag{2}$$

The degree of possibility of $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \sup_{x \geq y}\left[\min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \tag{3}$$

When a pair (x, y) exists such that $x \geq y$ and $\mu_{M_1}(x) = \mu_{M_2}(y)$, then we have $V(M_1 \geq M_2) = 1$. Since M_1 and M_2 are convex fuzzy numbers we have that:

$$V(M_1 \geq M_2) = 1 \qquad \text{if} m_1 \geq m_2 \tag{4}$$

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \mu_{M_1}(d) \tag{5}$$

where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}.When $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, the ordinate of D is given by:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \tag{6}$$

To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i $(i = 1, 2, ..., k)$ can be defined by:$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1)$ and $(M \geq M_2)$ and … and $(M \geq M_k)] = \min V(M \geq M_i)$,

$$i = 1, 2, ..., k. \tag{7}$$

Assume that

$$d'(A_i) = \min V(S_i \geq S_k) \tag{8}$$

For $k = 1, 2, \ldots, n; k \neq i$. Then the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \tag{9}$$

where A_i $(i = 1, 2, \ldots, n)$ are n elements.Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \tag{10}$$

where W is a non-fuzzy number.

ANP provides a general framework to deal with decisions without making assumptions about the independence of higher-level elements from lower-level elements and about the independence of the elements within a level [44, 45]. The ANP is the general form of the analytic hierarchy process, which has been used for multi-criteria decision making to release the restriction of hierarchical structure and has been applied to project selection, product planning, strategic decision, and optimal scheduling [12]. Whereas AHP represents a framework with a uni-directional hierarchical AHP relationship, ANP allows for complex interrelationships among decision levels and attributes [46].

ANP comprises four major steps [7]:

- Step 1: Model construction and problem structuring: The hierarchical structure is established. The model is formed with a goal, criteria, attributes, and alternatives like AHP.
- Step 2: Pairwise comparisons matrices and priority vectors: Like AHP, pairwise comparison in ANP is performed in a matrix framework, and a local priority vector can be determined as an estimate of the relative importance of the elements being compared
- Step 3: Super matrix formation: If the criteria are interrelated, then a network replaces the hierarchy.
- Step 4: Selection of the best alternatives: At the end of the study, the alternative with the highest overall priority should be selected.

5 Case study

The logistic sector is a very popular in Turkey. It is a developing sector. That is why; the logistic firms which supplied the companies' logistic activities have to be very competitor. In this paper, three alternative suppliers are evaluated. Suppliers I, II, and III are compared to select the best supplier among the three.

5.1 Application and discussion of Fuzzy AHP in supplier selection problem

The fuzzy evaluation matrix relevant to the goal is given in Table 1. After this, the decision-making group compares the attributes with respect to criteria. First, they compare the attributes of service quality and then the other matrices of pairwise comparisons are made and the weight vector of each matrix is calculated. All the attributes are compared under each of the criteria separately by following the same procedure as below.

Finally, the priority weights of each supplier can be calculated by weights per alternative multiplied by weights of the corresponding criteria. The combination of priority

Table 1 The fuzzy evaluation matrix with respect to the goal

	Service quality	Cost	Risk factors	Supplier's characteristics
Service quality	(1, 1, 1)	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)	(5/2, 3, 7/2)
Cost	(2/5, 1/2, 2/3)	(1, 1, 1)	(2/7, 1/3, 2/5)	(3/2, 2, 5/2)
Risk factors	(3/2, 2, 5/2)	(5/2, 3, 7/2)	(1, 1, 1)	(7/2, 4, 9/2)
Supplier's characteristics	(2/7, 1/3, 2/5)	(2/5, 1/2, 2/3)	(2/9, 1/4, 2/7)	(1, 1, 1)

From Table 1, S_{SQ}=(5.40, 6.50, 7.67) ⊗ (1/26.09, 1/22.42, 1/18.99)=(0.21, 0.29, 0.40); S_C=(3.19, 3.83, 4.57) ⊗ (1/26.09, 1/22.42, 1/18.99)=(0.12, 0.17, 0.24); S_R=(8.50, 10.00, 11.50) ⊗ (1/26.09, 1/22.42, 1/18.99)=(0.33, 0.45, 0.61); S_{SC}=(1.91, 2.08, 2.35) ⊗ (1/26.09, 1/22.42, 1/18.99)=(0.07, 0.09, 0.12) are obtained. Using these factors, $V(S_{SQ} \geq S_C)$=1.00, $V(S_{SQ} \geq S_R)$=0.33, $V(S_{SQ} \geq S_{SC})$=1.00, $V(S_C \geq S_{SQ})$=0.22, $V(S_C \geq S_R)$=0.45, $V(S_C \geq S_{SC})$=1.00, $V(S_R \geq S_{SQ})$=1.00, $V(S_R \geq S_C)$=1.00, $V(S_R \geq S_{SC})$=1.00, $V(S_{SC} \geq S_{SQ})$=0.73, $V(S_{SC} \geq S_C)$=0.02, $V(S_{SC} \geq S_R)$=1.00 are obtained. Thus, the weight vector from Table 1 is calculated as W_G=(0.21, 0.14, 0.64, 0.01)^T

weights of alternatives to determine priority weights for the best supplier is given in Table 2.

Evaluating the combination of priority weights for attributes, criteria, and alternatives to determine priority weights, we find that the Supplier II is the best supplier for our sample company.

5.2 Application and discussion of Fuzzy ANP in supplier selection problem

After all calculations, we start to develop the fuzzy AHP methodology due to its needs. While the AHP represents a framework with a uni-directional hierarchical AHP relationship, the ANP allows for complex interrelationships among decision levels and attributes. Now, we continue our calculations with the inner dependence matrix of all factors. Firstly, in Table 3, the inner dependence matrix of the factors with respect to service quality is represented. The other inner dependence matrices are shown in Tables 4, 5, and 6.

Now, all the inner dependence matrices are formed. Interdependent weights of the factors are computed by multiplying the dependence matrix of the factors which we obtained with the local weights of factors provided in Table 1. The interdependent weights of the factors are calculated as follows:

$$\begin{bmatrix} \text{servicequality} \\ \text{cost} \\ \text{risk} \\ \text{characteristics} \end{bmatrix} = \begin{bmatrix} 1.00 & 0.81 & 0.70 & 0.77 \\ 0.33 & 1.00 & 0.15 & 0.02 \\ 0.09 & 0.17 & 1.00 & 0.21 \\ 0.58 & 0.02 & 0.15 & 1.00 \end{bmatrix} \times \begin{bmatrix} 0.21 \\ 0.14 \\ 0.64 \\ 0.01 \end{bmatrix} = \begin{bmatrix} 0.39 \\ 0.15 \\ 0.34 \\ 0.12 \end{bmatrix}$$

Significant differences are observed in the results obtained for the factor weights when the interdependent weights of the factors calculated. The results change from 0.21 to 0.39, 0.14 to 0.15, 0.64 to 0.34, and 0.01 to 0.12, for the weight values of factors service quality, cost, risk factors, and supplier's characteristics, respectively.

Using interdependent weights of the criteria and local weights attributes, global weights for the attributes are calculated. Global attributes weights are computed by multiplying local weight of the attributes with the interdependent weight of the criteria to which it belongs.

Finally, the overall priorities of the alternative suppliers, reflecting the interrelationships within the criteria are calculated by multiplying weight vectors of attributes and global weights of attributes. The calculation is shown as follows:

$$\begin{bmatrix} \text{weight} \\ \text{vectors} \\ \text{of} \\ \text{attributes} \end{bmatrix} \times \begin{bmatrix} \text{global} \\ \text{weight} \\ \text{of} \\ \text{attributes} \end{bmatrix} = \begin{bmatrix} 0.22 \\ 0.54 \\ 0.24 \end{bmatrix}$$

Table 2 Combination of criteria of the goal

	Service quality	Cost	Risk factors	Supplier's characteristics	Alternative priority weight
Weight	0.21	0.14	0.64	0.01	
Alternative strategies					
Supplier I	0.09	0.64	0.20	0.22	0.23
Supplier II	0.64	0.15	0.56	0.65	0.52
Supplier III	0.27	0.21	0.24	0.13	0.25

From Table 6, [(0.09×0.21)+(0.64×0.14)+(0.20×0.64)+(0.22×0.01)]=0.23; [(0.64×0.21)+(0.15×0.14)+(0.56×0.64)+(0.65×0.01)]=0.52; [(0.27×0.21)+(0.21×0.14)+(0.24×0.64)+(0.13×0.01)]=0.25 are obtained

Table 3 The inner dependence matrix of the factors with respect to service quality

	Cost	Risk factors	Supplier's characteristics
Cost	(1, 1, 1)	(3/2, 2, 5/2)	(2/7, 1/3, 2/5)
Risk factors	(2/5, 1/2, 3/2)	(1, 1, 1)	(2/9, 1/4, 2/7)
Supplier's characteristics	(5/2, 3, 7/2)	(7/2, 4, 9/2)	(1, 1, 1)

W_1=(0.33, 0.09, 0.58)^T

Table 4 The inner dependence matrix of the factors with respect to cost

	Service quality	Risk factors	Supplier's characteristics
Service quality	(1, 1, 1)	(3/2, 2, 5/2)	(5/2, 3, 7/2)
Risk factors	(2/5, 1/2, 3/2)	(1, 1, 1)	(3/2, 2, 5/2)
Supplier's characteristics	(2/7, 1/3, 2/5)	(2/5, 1/2, 3/2)	(1, 1, 1)

$W_2=(0.81, 0.17, 0.02)^T$

Table 6 The inner dependence matrix of the factors with respect to supplier's characteristics

	Service quality	Cost	Risk factors
Service quality	(1, 1, 1)	(7/2, 4, 9/2)	(2/7, 1/3, 2/5)
Cost	(2/9, 1/4, 2/7)	(1, 1, 1)	(2/9, 1/4, 2/7)
Risk factors	(5/2, 3, 7/2)	(7/2, 4, 9/2)	(1, 1, 1)

$W_4=(0.77, 0.02, 0.21)^T$

5.3 Comparisons of the results

The fuzzy ANP analysis results indicate that Supplier II is the best supplier with an overall priority value of 0.54. The results obtained from the fuzzy AHP and fuzzy ANP are compared in Table 7.

In both methods, Supplier II is the best one among the alternatives. In fuzzy AHP method, risk factor is the most effective criterion on this result. Service quality, cost, and supplier's characteristics follow this criterion. On the other hand, in fuzzy ANP method, the most effective criterion is service quality. Risk factor, cost, and supplier's characteristics follow this criterion.

6 Conclusion

In a global supply chain management, selecting the most appropriate partners is the crucial first step. That is why the main objectives of this paper are to highlight the importance of both supply chain management and the biggest problem selection of the best and the most suitable supplier in global supply chain systems. In the competitive world, global corporations need a methodology to evaluate the suppliers and to configure global logistics systems efficiently.

In this paper, we proposed a model for selecting of the best supplier in a global supply chain. We use linguistic variable weight methods to solve our problem and to avoid the mistake of decision-making.

Table 5 The inner dependence matrix of the factors with respect to risk factors

	Service quality	Cost	Supplier's characteristics
Service quality	(1, 1, 1)	(3/2, 2, 5/2)	(3/2, 2, 5/2)
Cost	(2/5, 1/2, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
Supplier's characteristics	(2/5, 1/2, 3/2)	(2/3, 1, 3/2)	(1, 1, 1)

$W_3=(0.70, 0.15, 0.15)^T$

Multi-criteria decision-making techniques have the advantage that they can assess a variety of options according to a variety of criteria that have different units. This is a very important advantage over traditional decision aiding methods where all criteria need to be converted to the same unit. Another significant advantage of multi-criteria decision-making techniques is that they have the capacity to analyze both quantitative and qualitative evaluation criteria together [47]. With these advantages, the both multi-criteria decision-making techniques such as analytical hierarchy process and analytical network process were used in this paper.

In the world, every country's situation may be different and would need to be understood by both supplier and manufacturer for managing the supply chain effectively. There may be different perceptions from country to country on how to effectively manage a supply chain. In this paper, we analyzed the criteria which directly and indirectly affect the supplier selection problem. With this process, the manufacturers can manage their supply chains properly.

In future research, the model can be improved than the model was presented in this paper and also in the future researches for evaluating the suppliers and deciding to the most suitable suppliers other evaluation methodologies can be used.

In conclusion, the managers do not forget the supply chain competences' positive effects on their companies' organizational performance and profitability. Furthermore, the managers need to focus on developing such competencies to selecting the best supplier and building the global supply chain system successfully.

Table 7 Weights and ranking of the strategies with AHP and ANP

	S_1—Supplier I	S_2—Supplier II	S_3—Supplier III
Weights in AHP	0.23	0.52	0.25
Ranking in AHP	3	1	2
Weights in ANP	0.22	0.54	0.24
Ranking in ANP	3	1	2

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