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A fuzzy multi-criteria decision model for integrated suppliers selection and optimal order allocation in the green supply chain

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A B S T R A C T

Today, with the advancement of technology in the production process of various products, the achievement of sustainable production and development has become one of the main concerns of factories and manufacturing organizations. In the same vein, many manufacturers try to select suppliers in their upstream supply chains that have the best performance in terms of sustainable development criteria. In this research, a new multi-criteria decision-making model for selecting suppliers and assigning orders in the green supply chain is presented with a fuzzy optimization approach. Due to uncertainty in supplier capacity as well as customer demand, the problem is formulated as a fuzzy multi-objective linear programming (FMOLP). The proposed model for the selection of suppliers of SAPCO Corporation is evaluated. Firstly, in order to select and rank suppliers in a green supply chain, a network structure of criteria has defined with five main criteria of cost, quality, delivery, technology and environmental benefits. Subsequently, using incomplete fuzzy linguistic relationships, pair-wise comparisons between the criteria and sub-criteria as well as the operation of the options will be assessed. The results of these comparisons rank the existing suppliers in terms of performance and determine the utility of them. The output of these calculations (utility index) is used in the optimization model. Subsequently, in the order allocation process, the two functions of the target cost of purchase and purchase value are optimized simultaneously. Finally, the order quantity is determined for each supplier in each period.

1. Introduction

Supply chain management is the process of planning, executing and controlling supply chain operations that are optimally carried out. Supply chain management has the task of integrating organizational units throughout the supply chain and coordinating the flow of materials, information, and finance to meet the final customer demand with the aim of improving the supply competitiveness, and all activities related to the flow and conversion of commodities from the raw material stage. Recently, with the presence of the concept of supply chain management, researchers have found that choosing the

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appropriate supplier and managing it is an approach that can be used to increase the supply chain competitiveness (Stadtler, 2015; Yan, 2009).

Today, suppliers play an important role in achieving key supply chain performance goals. Recently, the green supply chain is a type of supply chain in which the requirements and environmental requirements are taken into consideration. In the research, several definitions have been presented for managing the green chain (Fahimnia et al., 2015). Green supply chain management includes activities such as green purchase, green design, green operations, green production, logistics and green distribution. The concept of green supply chain covers the environmental effects of a product at all stages of its life cycle, from raw material extraction to design and production, and ultimately eliminating the product. The point that is seen in most of the definitions is that all of them believe that the concept of green supply chain management emanates from both environmental management and supply chain management. The addition of the green component to the supply chain management is the consideration of existing relationships between supply chain management and the environment.

Within the supply chain management chain, choosing suppliers is critical for purchasing managers and operational managers and helping organizations maintain their competitive position. Suppliers' assessment needs to take into account both tangible and intangible factors that are sometimes not clearly defined. In this research, a multi-objective decision-making model for selecting suppliers and assigning orders in a supply chain with a fuzzy approach is presented.

This research has the following contributions: (1) we provide a fuzzy multi-objective linear programming (FMOLP) model to determine the order quantity of each supplier in each period, and ranking the existing suppliers in terms of performance and (2) the proposed method takes into account the uncertainty in the supplier's capacity as well as customer demand.

2. Literature review

In general, as the problem implies, during the supplier selection, we have a set of choices, according to the needs of our organization. The goal is to select the best suppliers in terms of a defined set of criteria. Such a problem is one of multi-attribute decision-making (MADM) problems. The nature of the supplier selection in the supply chain is also a multi-objective decision-making (MODM) problem with multiple criteria that can be quantitative or qualitative (Govindan et al., 2015). MCDM is an effective framework for comparing suppliers based on the evaluation of various criteria. The application of a variety of multi-criteria decision-making methods has been of interest to researchers. Under many conditions, definitive data are not sufficient to model actual conditions, since human priorities are often non-existent and cannot be estimated with precise numbers.

In recent years, the process of fuzzy sets has been used to select the suppliers, which is a realistic process that uses linguistic values instead of numerical values, and the weight of the criteria is expressed in terms of linguistic values and depending on the judgment of individuals, weights are not equal to the value (Büyüközkan & Göçer, 2017).

In order to use the techniques in the MCDM, it is necessary to determine the set of criteria for selection, and the various alternatives are scored based on whether or not these criteria are met. This score should be made by a set of decision-makers. As noted, in some cases the organization needs to rank a number of suppliers and determine the number of orders for each one. In this case, the use of optimization techniques in MCDM, such as fuzzy multi-objective programming can be used by decision-makers (see Table 1).

Traditional supplier selection methods have often focused on price estimators in supplier evaluation (Degraeve & Roodhooft, 1999). However, factories have realized that the selection of suppliers can only damage their performance based on a single criterion. In previous research, various criteria have been developed for the assessment and selection of suppliers (Dickson, 1996). Weber et al. (1991) reviewed widespread work from 1966 onwards, concluding that quality, cost, and timely delivery are three of the most commonly used criteria in supplier selection problems. Different models are currently being developed for assessing suppliers in various papers such as Analytical Hierarchy Process (AHP), ANP, ideal planning, clustering methods, human judgment models, statistical analysis models and neural networks (Chai et al., 2013).

Supplier selection processes typically include opposed goals, in which case MCDM models can be used. AHP, introduced by the time of 1997, is a popular technique in multicriteria decision-making, which is suited to combine quantitative and qualitative criteria. This approach has previously been used to rank potential suppliers in a hierarchical structure (Azar et al., 2015). In order to determine the weight of each of these indexes, it is necessary to have a technique that can determine the weight of each indicator according to expert judgments. Analytical Hierarchy Process (AHP) by performing pseudo-comparative tests based on mental judgments is an appropriate technique for determining the weight of criteria, but this technique is not able to analyze feedback relationships between criteria in the form of a general network. Therefore, the analytical network analysis process (ANP), a more general form of AHP, is used. In this paper, all relationships and correlations between network components are evaluated by AHP's paired-wise comparisons and the so-called large matrix method.

Table 1
Taxonomy of the related paper

Authors	Approaches	Uncertainty	Application	Multi-objective optimization
Thongchattu & Siripokapirom (2010)	AHP and ANN	-	manufacturing	-
Yan (2009)	AHP and GA	-	manufacturing	-
Kuo et al. (2010)	ANN-MADA	-	Digital Camera Manufacturing Company in Taiwan	-
Kuo & Lin (2012)	DEA and ANP	-	High-tech Industry	-
Wen & Chi (2010)	DEA with AHP and ANP	-	manufacturing	-
Chen et al. (2010)	Fuzzy Set Theory and Grey Relational Analysis	√	Electronics Industry- PCB Firm	-
Li & Zhao (2009)	Grey Correlational Analysis (GCR) and AHP-	-	Electronics Company	-
Humphreys et al. (2003)	Knowledge-based system and Case based reasoning	-	Telecommunication company	-
Kannan et al. (2013)	FAHP + multi-objective programming	-	automobile manufacturing	√
Sivrikaya et al. (2015)	FAHP +goal programming	√	manufacturing	-
Foroozesh et al. (2017)	Fuzzy Group Decision Model	√	manufacturing	-
Beheshtinia & Nemati (2017)	Hybrid Fuzzy Multi-Criteria Decision-Making Model	√	Advertising industry	-
Qin et al. (2017)	TODIM multi-criteria group decision making method	√	automobile manufacturing	-
Prasad et al. (2017)	DEA-AHP-Grey Relational Analysis (GRA)	-	steel	-
this study	FANP + FMOLP	√	automobile manufacturing company	√

3. Research method

Fig. 1 shows the overall process of supplier selection and order assignment. As can be seen in the figure, in order to select suppliers, using the conceptual methods first, the criteria are determined and their significance is determined. Then, with the use of a fuzzy multi-objective optimization model, the order quantity is determined for each supplier.

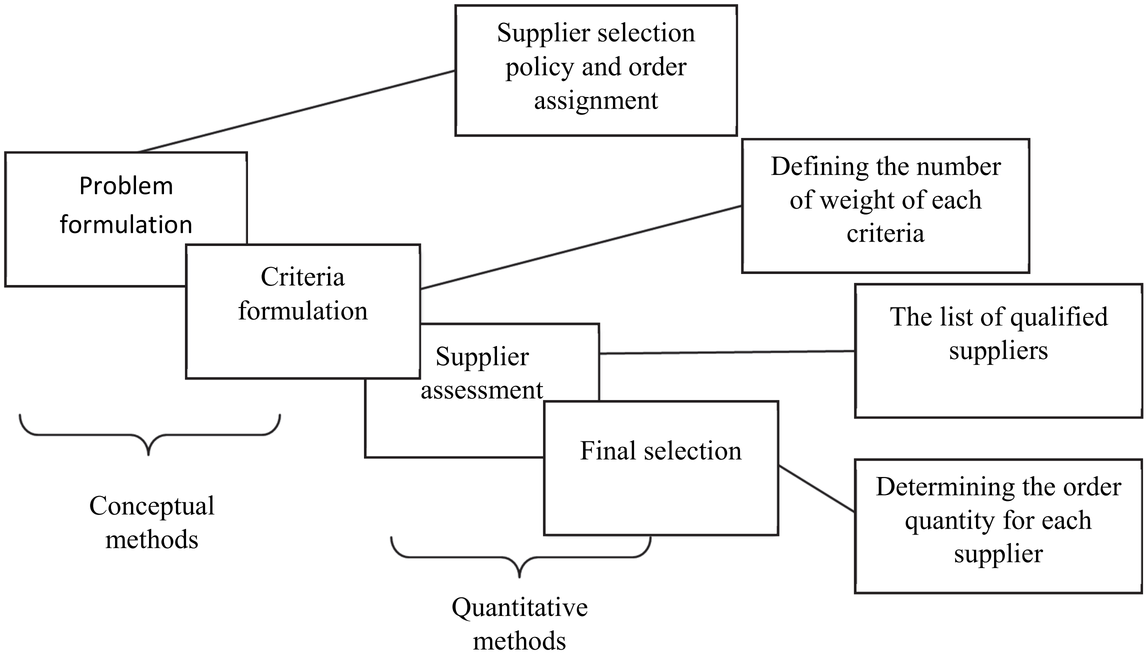

Fig. 1. The general framework for supplier selection and order assignment

3.1. Fuzzy analytical network process (ANP)

Given the huge range of products needed, choosing the right suppliers and setting the order for them for each of these products is one of the main decisions in supply chain management. Meanwhile, by changing the standard rules related to the environmental performance of factories and manufacturing organizations, environmental considerations, along with traditional criteria such as quality and delivery and cost, constitute the main criteria for selecting suppliers. This is clearly the case for selecting suppliers of products such as tires with very significant environmental impacts. In this research, the criteria used in a study by Kannan et al. (2013) is used. These criteria are cost, quality, delivery, technological capabilities and environmental benefits. In this research, each of these criteria is itself made up of several sub-criteria. In this research, using the ANP method, the relationship between the sub-criteria is examined. The structure of the network used in this research is depicted in Fig. 2. As can be seen in this figure, the sub-criteria of each criterion are interconnected, which leads to some kind of independence from the main criteria.

The analytical network process has been extensively used to solve MCDM problems in which the criteria are not independent. ANP can overcome one of the hierarchical analysis constraints, assuming the independence of the criteria and alternatives. According to the principle of correlation, the elements of each level depend only on the higher level elements, that is, the coefficients of the importance of the elements of each level are necessarily determined on the basis of the higher level, whereas in most cases, there is a reciprocal relationship and correlation between decision alternatives and decision criteria. ANP can be used as a useful tool in the issues that interact between the elements of the system forming a network structure.

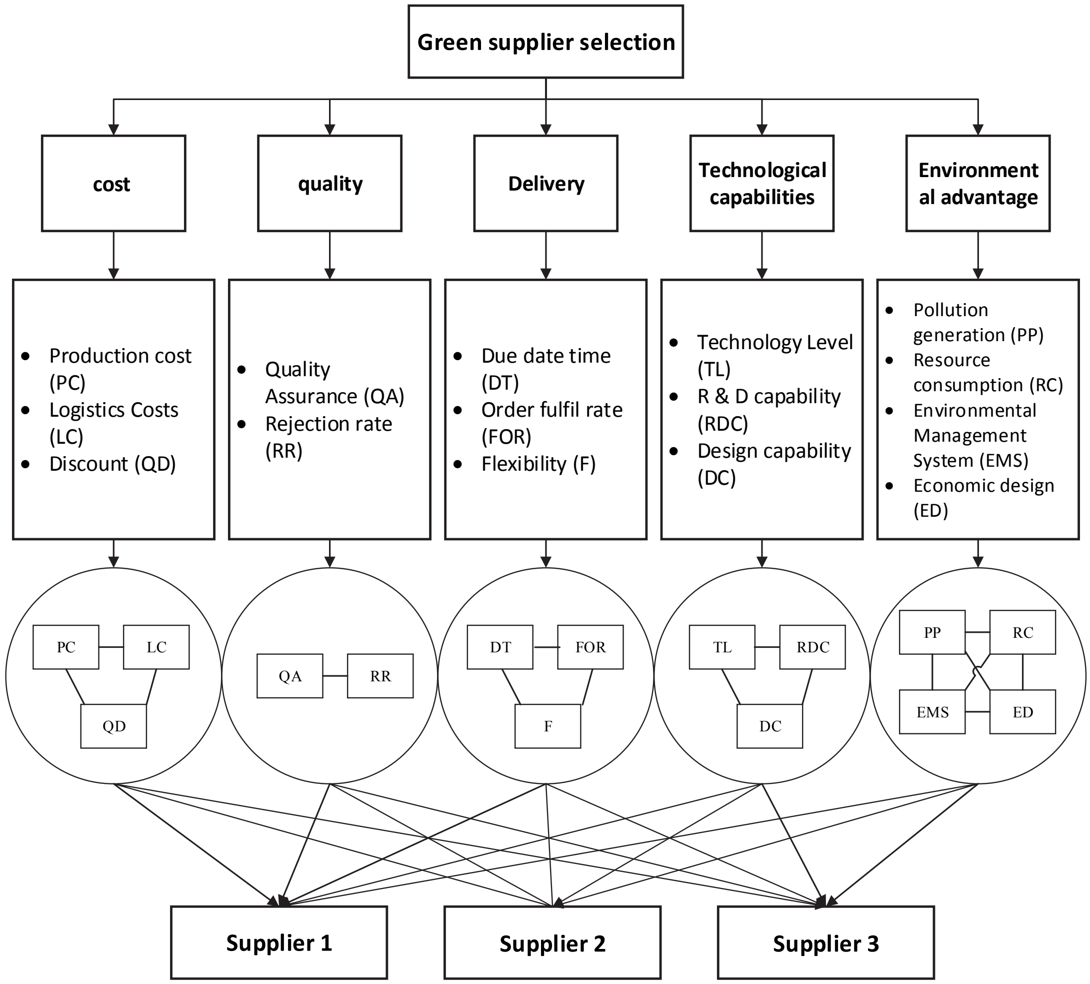

Fig. 2. The ANP model of supplier selection for the green supply chain

3.2. Fuzzy ranking

Several methods have been proposed by many researchers using the two fuzzy systems and AHP or ANP, often referred to as FAHP or FANP systems, based on the use of fuzzy comparative matrices. Buckley (1985) used the geometric mean method to calculate fuzzy weights. Chang (1996) proposed an extended AHP method that resulted in definite weights for the fuzzy matrix. Buckley et al. (2001) presented the extended λ_{max} method, which is the fuzzy method of the well-known λ_{max} method. In this method, the fuzzy numbers $U_{ij} = (l_{ij}, m_{ij}, u_{ij})$ with matrix drives a_{ij} so that:

$$U_{ij}= (l_{ij} , m_{ij} , u_{ij}) : l_{ij} \leq m_{ij} \leq u_{ij} , l_{ij} , m_{ij} , u_{ij} \in [1/9,9]$$
$$l_{ij}= \min(B_{ijk}) \quad , \quad m_{ij}=\sqrt[n]{\prod_1^n B_{ijk}} \quad , \quad u_{ij}=\max(B_{ijk}) \tag{1}$$

In which B_{ijk} is the relative importance of i^{th} criterion comparing to the j^{th} criterion given by the expert. The geometric mean method is used to defuzzificates this matrix and obtain the priority of each criterion. In multi-criteria decision-making problems, we consider a set of alternatives $A_1, A_2 \dots A_m$, and criteria $C_1, C_2 \dots C_n$. In addition, there are k decision-makers that determine the importance of the alternative regarding all criteria as well as the weight of the criteria. The data are summarized in a matrix below:

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \cdots & \cdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array}$$

3.3. Fuzzy pairwise comparison matrix

Suppose ${x_{ij}}^k$ as the importance given by the decision maker k to alternative A_i relative to criterion C_j. In addition, $w_{jt} = (a_{jt}, b_{jt}, c_{jt}),\ j = 1,2,\dots,n,\ t = 1,2,\dots,k$ is the weight of criterion j, which is attributed by the t[th] decision maker. The degree of importance of the criteria relative to the alternative and the weight of each criterion is expressed as a triangular fuzzy number. To obtain the significance and overall weight we perform the following calculations:

$$\tilde{x}_{ij} = \frac{1}{k}\sum_{l=1}^{c} {x_{ij}}^{(l)} \tag{2}$$

$$\widetilde{w}_{it} = \frac{1}{k}\sum_{l=1}^{c} {w_{it}}^{(l)} \tag{3}$$

3.4. Incomplete linguistic variables in fuzzy calculations

Experts and decision makers may not be able to comment in all areas for reasons such as lack of sufficient knowledge or decision-making under time and cost pressures. Therefore, using the incomplete language preferences approach in fuzzy logic and using a network tool such as ANP, it is possible to calculate those pairwise comparisons that are not performed by the experts. To better understand the process of implementing these steps, concepts of fuzzy relations, as well as a fuzzy relationship with a transitive property, are presented.

Definition: If the full fuzzy preference relationship P satisfies the incremental transitive property $p_{ij} + p_{ji} = 1, p_{ii} = 0.5$ for all *j* and *i*, then there is a complete fuzzy preferential relationship with incremental compatibility.

The first step begins with defining the criteria and sub-criteria and making comparisons. Here, because of the use of language preference values, P is the comparisons matrix in which all the elements contain values between $[0,1]$. **Table 2** shows how to express fuzzy language preferences. But, these comparisons are not done completely. Therefore, in the comparisons matrix, there are empty cells. In the second step, these values are determined using incomplete preferential relationships.

Table 2
Define fuzzy scales for linguistic variables

Linguistic variables	Fuzzy scale
No effect	(0,0,0.1)
Very little effect	(0,0.1,0.3)
Little effect	(0.1,0.3,0.5)
Normal effect	(0.3,0.5,0.7)
Great effect	(0.5,0.7,0.9)
Very much effect	(0.7,0.9,1)
Most Effect	(0.9,1,1)

After designing the fuzzy matrix, it is necessary to calculate its unknown values. For doing this we use the following integral:

$$F(\tilde{p}_{ij}) = \frac{1}{2}\int_0^1 (\inf_{x\in\Re}\tilde{p}_{ij} + \sup_{x\in\Re}\tilde{p}_{ij})d\alpha\,. \tag{4}$$

The calculation of these values is performed according to the ultimate goal of maximizing the level of consistency of expert opinions and using incremental property.

$$p_{ij} = p_{iy} + p_{yj} - 0.5, \quad \forall i,j \in \{1,2,\dots,n\} \tag{5}$$

3.5. Computation of the inconsistency rate

According to the Eq. (5), we can estimate the unknown values of the P matrix. This can, of course, depend on the elements used in the formula, and therefore, depending on the element, the consistency rate can be calculated with one of the three following equations:

$$H_{ij}^1 = \{y \neq i,j \mid (i,y),(y,j) \in EV\} \tag{6}$$

$$H_{ij}^2 = \{y \neq i,j \mid (y,i),(y,j) \in EV\} \tag{7}$$

$$H_{ij}^3 = \{y \neq i,j \mid (i,y),(j,y) \in EV\} \tag{8}$$

In the next step, it is necessary to check the consistency rate. As can be seen, according to the type of interface option, the calculation method is performed in one of three ways. Therefore, in calculating the level of compatibility, these three modes should be considered. The consistency rate for each element the comparison matrix is calculated through the following equation:

$$CL_{ij} = (1-\alpha_{ij})(1-\varepsilon p_{ij}) + \alpha_{ij}\frac{CP_i + CP_j}{2}, \tag{9}$$

which is, in fact, a linear combination of the mean value of the completeness of the preferential relationships for each alternative (CP_i). These preference values are calculated by the following equation:

$$CP_i = \frac{\#EV_i}{2(n-1)} \tag{10}$$

εp_{ij} is the error value associated with the inconsistency rate. To calculate it, the following equations are used:

$$\varepsilon p_{ij} = \frac{2}{3}\times\frac{\varepsilon p_{ij}^1 + \varepsilon p_{ij}^2 + \varepsilon p_{ij}^3}{\kappa}, \quad \varepsilon p_{ij}^l = \begin{cases} \dfrac{\sum_{j\in H_{ij}^l} |cp_{ij}^l - p_{ij}|}{H_{ij}^z}, & if\ (H_{ij}^z \neq 0); z \in \{1,2,3\} \\ 0 & otherwise \end{cases} \tag{11}$$

Furthermore, α_{ij} is a parameter that is used to control the degree of effectiveness of the completeness of alternatives on the inconsistency rate.

$$\alpha_{ij} = 1 - \frac{EV_i + EV_j - (EV_i \cap EV_j)}{4(n-1)-2} \tag{12}$$

To determine the compatibility of p_{ij} comparisons, the calculated CL_{ij} should not be less than 0.5. If p_{ij} is not compatible and $\varepsilon_{ij} \neq 0$ then the decision maker should review its judgments and change the preferences. If p_{ij} is not compatible, $\varepsilon_{ij} = 0$ then the values must be increased.

4. Integrated supplier selection and order allocation model

After determining the utility of each supplier, the order quantity from each supplier can be determined by means of an integrated supplier selection and order assignment model. The proposed model in this research is the development of work by Demirtas and Üstün (2008). The development of this model is one of the innovations of this research, considering the uncertainty of the problem (including suppliers' capacity as well as customer demand) and formulating it as a fuzzy program. In Table 3, the indices and variables in the mathematical model are defined.

Table 3
The notation of mathematical model

Symbol	Description
i	Index of suppliers
t	Index of time period
X_{it}	Order quantity to supplier *i* at period *t*
Y_{it}	=1 if an order is placed for supplier *i* during period *t,* and 0 otherwise
P_{it}	Price per unit of product for the supplier *i* in the period *t*
O_{it}	Ordered cost to the supplier *i* during the period *t*
L_{it}	The percentage of products from the supplier *i* in period *t* that is delayed
DT_i	The provisional delay for supplier *i*
T_{it}	The cost of transporting each item from the supplier *i* that takes place in period *t*
P'	Daily delay cost of a product
h_{I_t}	Inventory cost in period *t*
W_i	The utility of supplier *i*
$Cmax_i$	Maximum supply capacity of supplier *i*
$Dmax_t$	Maximum demand during period *t*
q_{it}	The percentage of products from the supplier in period *t*, which does not have the required quality

4.1 Order assignment model

In assigning orders to suppliers, the organization seeks to optimize two objective functions, simultaneously. The first is minimizing total costs and the second goal is to maximize the value of purchases using utility indicators. The cost function, the total cost of purchasing items, the order, the lateness, quality, and ultimately the shipping, are included. The problem is presented in the form of a Fuzzy Multi-objective Linear Programming Model (FMOLP). Factors such as the demand and capacity of suppliers that were considered definitively in previous studies are random and variable here. Given the above-mentioned points, the problem is a complex mixed-integer linear programming problem (MILP) as follows:

$$\min F_1(\mathbf{X},\mathbf{Y}) = \sum_{i=1}^{n}\sum_{t=1}^{m} P_{it}X_{it} + \sum_{i=1}^{n}\sum_{t=1}^{m} O_{it}Y_{it} + \sum_{i=1}^{n}\sum_{t=1}^{m} L_{it}X_{it}P'DT_i + \sum_{i=1}^{n}\sum_{t=1}^{m} T_{it}X_{it} + \sum_{t=1}^{m} h_{I_t} \quad (13)$$

$$\text{Max } F_2(\mathbf{X}) = \sum_{i=1}^{n}\sum_{t=1}^{m} W_iX_{it} \quad (14)$$

$s.t.$

$$\sum_{t=1}^{m} X_{it} \le Y_{it}Cmax_i \ , \qquad \forall i \quad (15)$$

$$\sum_{i=1}^{n} X_{it} + I_{t-1} \ge Dmax_t \ , \qquad \forall t \quad (16)$$

$$I_t = I_{t-1} + \sum_{i=1}^{n} X_{it} - Dmax_t \ , \qquad \forall t \quad (17)$$

$$\sum_{i=1}^{n} q_{it} X_{it} \le QDmax_t \tag{18}$$

$$i = \{1,2,3\}, t = \{1,2,3,4,5,6\}$$
$$X_{it} \ge 0 \ , \qquad Y_{it} \in \{0,1\} \tag{19}$$

Eq. (13) and Eq. (14) represent target functions related to costs and value of the purchase, respectively. Constraint (15) is related to production capacity limitation. The Eq. (16) corresponds to the satisfaction of the demand limitation in each period. Eq. (17) shows the amount of inventory in each period, and the Eq. (18) is the quality-related constraint.

4.2 Uncertainty modeling

As mentioned in the main model, the problem, demand, and capacity of suppliers are random, that is, they do not necessarily reach the maximum amount of demand or capacity at each level. For this reason, for these two values, a tolerance limit is defined, in which the values of each one are determined by the experts. Thus, the constraints (15) through (18) are formulated as follows:

$$\sum_{t=1}^{m} X_{it} \le Y_{it}(C_i + C') \ , \qquad \forall i \tag{20}$$

$$\sum_{i=1}^{n} X_{it} + I_{t-1} \ge D_t + D' \, , \qquad \forall t \tag{21}$$

$$I_t = I_{t-1} + \sum_{i=1}^{n} X_{it} - D_t - D' \, , \qquad \forall t \tag{22}$$

$$\sum_{i=1}^{n} q_{it} X_{it} \le Q(D_t + D') \, , \qquad \forall t \tag{23}$$

In Eqs. (20), C 'and D' are tolerances related to production capacity and demand, respectively. Now, the model needs to be expressed as a linear multi-objective programming. For this purpose, the fuzzy linear programming model introduced by Zimmermann (1978) is used.

$$max\ \lambda$$
$$s.t. \tag{24}$$
$$\lambda\left(Z_j^{max}(x) - Z_j^{min}(x)\right) + Z_j(x) \le Z_j^{max}(x) \tag{25}$$
$$\lambda(d_k) + g_k(x) \le b_k + d_k \tag{26}$$
$$Ax \le b \tag{27}$$
$$x \ge 0 \tag{28}$$

In the above model, $Z_j^{max}(x)$ and $Z_j^{min}(x)$ are the maximum and minimum values of the j^th^ objective function. For a function that we intend to minimize, Z_j^{min} is obtained from solving a single-objective model, and vice versa. For the case in which the maximum value of our optimal value is Z_j^{max}, we calculate this way. For example, we have a target minimizing function and a target maximizing function. We put each one separately in the original model (which is definite) and solve it. Thus $f_1^{min}(x_1^*)$ and $f_2^{max}(x_2^*)$ are computed. The solution obtained in each mode is included in the other target function, so that f_2^{min} and f_1^{max} are also calculated. Finally, the fuzzy model of the main problem is formulated as follows:

$$\max \lambda \qquad (29)$$
$$\boldsymbol{s.t.}$$
$$\lambda\left(f_1^{max}(x) - f_1^{min}(x)\right) + f_1(x) \le f_1^{min}(x) \qquad (30)$$
$$\lambda\left(f_2^{max}(x) - f_2^{min}(x)\right) + f_2(x) \le f_2^{max}(x) \qquad (31)$$
$$\lambda(C') + \sum_{i=1}^{n} X_{it} \le Y_{it}(C_i + C') \qquad (32)$$
$$\lambda(D') + \sum_{i=1}^{n} X_{it} + I_{t-1} \ge D_t + D' \qquad (33)$$
$$\lambda(D') + I_t = \sum_{i=1}^{n} X_{it} + I_{t-1} - D_t - D' \qquad (34)$$
$$\lambda(D') + \sum_{i=1}^{n} q_{it} X_{it} \le Q(D_t + D') \qquad (35)$$
$$X_{it} \ge 0\ , \qquad Y_{it} \in \{0,1\} \qquad (36)$$

4. Case study: supplier selection in Automobile industry

SAPCO (Supplying Automotive Parts Company) is the exclusive supplier of automotive parts for Iran Khodro, the leading car manufacturer in the Middle East with more than 700 thousand produced cars annually. It has been established in 1994 by changing the name and statute of the company specializing in the automobile service company. Now, after 23 years, around 4200 local manufacturers are recognized by SAPCO and nearly 550 suppliers have a direct contract with the firm. At present, SAPCO's Supply chain is manufacturing locally more than 5000 different components. The SAPCO Corporation, in line with its mission and in order to achieve its vision, carries out tasks such as supplying parts and assemblies for automobiles to domestic and foreign automakers, identifies the sources of supply and evaluation of their capabilities, and chooses contractors and suppliers of procurement contracts. The supply chain examined in this study relates to the provision of Samand Automobile Tires. In the selection of suppliers, environmental criteria have been considered from the point of view of the green supply chain. In this regard, suppliers are selected to be superior in terms of pollution production standards, resource consumption, environmental management systems and green design principles. In the supply chain, three companies are considered as their main suppliers. In the following section, the views of a number of sales experts in this company, as an expert, were used to determine the criteria and their importance.

5. Results and discussion

In this section, the results of the fuzzy multicriteria decision-making model are presented for selection of suppliers and optimal order allocation in the green supply chain. The importance of each criterion, as well as the inner effects of sub-criteria, is calculated from the expert's point of view. In order to collect information, a questionnaire was sent to 15 qualified people with at least 10 years of experience in the automotive industry, with middle management posts and senior management positions and at least a bachelor's degree. The Eq. (1) has also been used to synthesize the scores.

The proposed fuzzy scale has been adopted from the study of Büyüközkan & Göçer (2017). The reason for this is the flexibility of this rating system in cases where decision-maker information is not complete in all areas and cannot be scored in all areas. In fuzzy logic, linguistic variables are expressed in terms of phrase and words.

In a case study in this study, given the fact that the topic of environmental benefits is relatively new, experts cannot comment on all aspects of it. Therefore, using incomplete judgment in this method, we can calculate the values that do not exist in the pairwise comparison matrix, in which the process was fully explained in the previous sections.

In the next step, the opinions of experts on the relative importance of the criteria towards each other in relation to the main objective, namely, the selection and ranking of suppliers in the sustainable supply chain, were examined. Pairwise comparison of the sub-criteria of the cost, quality, delivery time, technology and environment are presented in Table 5 to Table 9, respectively. Subsequently, the relative importance of the sub-criteria was determined relative to the related criteria and, finally, the internal feedback of the sub-criteria are provided in Table 10.

Table 4
Comparison of the relative importance of the main criteria for selecting the supplier

	Cost	Delivery	Quality	Technology	Environment
Cost	-	(0.5 0.7 0.9)	(0.1,0.3,0.5)	(0.3,0.50,0.7)	(0.1,0.3,0.5)
Delivery	(0.1,0.3,0.5)	-	(0,0.1,0.3)	(0.1,0.3,0.5)	(0.1,0.3,0.5)
Quality	(0.5,0.7,0.9)	(0.7,0.9,0.1)	-	(0.5,0.7,0.9)	(0.3,0.5,0.7)
Technology	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	-	(0.1,0.3,0.5)
Environment	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	-

Table 5
Paired-wise comparison of cost sub-criteria

	production cost	logistic cost	order discount
production cost	-	(0.5,0.7,0.9)	(0.5,0.7,0.9)
Logistic cost	(0.1,0.3,0.5)	-	(0.3,0.5,0.7)
Order discount	(0.1,0.3,0.7)	(0.3,0.5,0.7)	-

Table 6
Paired-wise comparison of quality sub-criteria

	Quality assurance	Rejection rate
Quality assurance	-	(0,0.1,0.3)
Rejection rate	(0.7,0.9,1)	-

Table 7
Paired-wise comparison of delivery sub-criteria

	Delivery due date	Order fulfil rate	Order flexibility
Delivery due date	-	(0.1,0.3,0.5)	(0.3,0.5,0.7)
Order fulfil rate	(0.5,0.7,0.9)	-	(0.7,0.9,1)
Order flexibility	(0.3,0.5,0.7)	(0.5,0.7,0.9)	-

Table 8
Paired-wise comparison of technology sub-criteria

	Technology level	Research and development capabilities	Design capabilities
Technology level	**-**	**(0.3,0.5,0.7)**	**(0.5,0.7,0.9)**
Research and development capabilities	(0.3,0.5,0.7)	-	(0.5,0.7,0.9)
Design capabilities	**(0.1,0.3,0.5)**	**(0.1,0.3,0.5)**	**-**

Table 9
Paired-wise comparison of environmental sub-criteria

	Pollution generation	Resource consumption	Environmental management system	Green design
Pollution generation	-	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
Resource consumption	(0.1,0.3,0.5)	-	(0.1,0.3,0.7)	(0.3,0.5,0.7)
Environmental management system	(0.3,0.5,0.7)	(0.5,0.7,0.9)	-	(0.5,0.7,0.9)
Green design	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.1,0.3,0.5)	-

Table 10
The weight of the main criteria

Criteria	Relative importance (P_j)
Cost	0.1804
Delivery	0.1163
Quality of service	0.2665
Technology	0.1804
Environmental advantages	0.2565

By calculating the eigenvector of each of the pairwise comparison matrices, the values of the dependency indices A_{kj}^{D} are obtained for each of the sub-criteria. For example, Table 12 shows the importance of sub criteria for the delivery criterion. If we want to compute the dependency indices related to its sub-criteria, we process the defuzzification phase using equation (4). It should be noted that the significance of each sub-criterion is considered to be 0.5 for itself. The non-fuzzy matrix of comparisons of the relative importance of the sub criteria of the delivery criterion is given in Table 11. Based on these data, the eigenvector for the comparisons matrix of the sub-criteria of the delivery criterion is provided in Table 12.

Table 11
Non-Fuzzy pairwise comparison matrix of relative importance of sub-criteria of delivery

	Delivery due date	Order fulfil rate	Order flexibility
Delivery due date	0.5	0.3	0.5
Order fulfil rate	0.7	0.5	0.9
Order flexibility	0.5	0.7	0.5

Table 12
Eigenvector for the comparisons matrix of the sub-criteria of the delivery criterion

Sub-criteria	Eigenvector
Delivery due date	0.248
Order fulfill rate	0.4074
Order flexibility	0.3446

The output of these calculations is used in the final table for calculating the utility index. This procedure is performed for all the sub-criteria of the main criteria. According to

Table 13 to Table 16, for the calculation of the independence index of each sub-criterion, a basic criterion is determined by the importance of sub-criteria relative to each other in the case in which one of them is controlled. For example, if we want to calculate the independence index for the benchmark criteria for environmental benefits, we will act as follows:

Table 13
The relative importance of environmental benefits criterion when green design criterion is under control

	Pollution generation	Resource consumption	Environmental management system
Pollution generation	-	(0.3,0.5,0.7)	(0.7,0.9,0.1)
Resource consumption	(0.3,0.5,0.7)	-	(0.5,0.7,0.9)
Environmental management system	(0.0,0.1,0.3)	(0.1,0.3,0.5)	-

Table 14
The relative importance of environmental benefits criteria when an environmental management system is under control

	Pollution generation	Resource consumption	green design
Pollution generation	-	(0.1,0.3,0.5)	(0.3,0.5,0.7)
Resource consumption	(0.5,0.7,0.9)	-	(0.3,0.5,0.7)
Green design	(0.3,0.5,0.5)	(0.1,0.3,0.5)	-

Table 15
The relative importance of sub-criteria for the environmental benefits criterion when the sub-criteria of resource consumption is under control

	Pollution generation	Environmental management system	green design
Pollution generation	-	(0.5,0.7,0.9)	(0.0,0.1,0.3)
Environmental management system	(0.3,0.5,0.7)	-	(0.1,0.3,0.5)
Green design	(0.7,0.9,1)	(0.5,0.7,0.9)	-

Table 16
The relative importance of the sub-criteria of the environmental benefits criterion when the sub-criteria of contamination production is under control

	Resource consumption	Environmental management system	Green design
Resource consumption	-	(0.1,0.3,0.5)	(0.3,0.5,0.7)
Environmental management system	(0.5,0.7,0.9)	-	(0.5,0.7,0.9)
Green design	(0.5,0.7,0.9)	(0.3,0.5,0.7)	-

According to the dependency index, we first calculate the values of each of the above matrices. These values will be entered into the original matrix. The original large normal matrix before the convergence is summarized in Table 17.

Table 17
The initial large normal matrix before convergence

	PC	LC	DO	DT	FOR	F	TL	RDC	DC	PP	RC	EMS	ED
PC	0	0.604	0.5	0	0	0	0	0	0	0	0	0	0
LC	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0
DO	0.5	0.395	0	0	0	0	0	0	0	0	0	0	0
DT	0	0	0	0	0.395	0.395	0	0	0	0	0	0	0
FOR	0	0	0	0.395	0	0.604	0	0	0	0	0	0	0
F	0	0	0	0.604	0.604	0	0	0	0	0	0	0	0
TL	0	0	0	0	0	0	0	0.604	0.5	0	0	0	0
RDC	0	0	0	0	0	0	0.75	0	0.5	0	0	0	0
DC	0	0	0	0	0	0	0.25	0.395	0	0	0	0	0
PP	0	0	0	0	0	0	0	0	0	0	0.361	0.2727	0.2643
RC	0	0	0	0	0	0	0	0	0	0.4209	0	0.2928	0.3895
EMS	0	0	0	0	0	0	0	0	0	0.3937	0.361	0	0.3462
ED	0	0	0	0	0	0	0	0	0	0.1854	0.278	0.4345	0

With the ability to convey the above matrix, we can calculate the convergent large matrix (Table 17). Finally, using the converted numbers calculated using the converted numbers; they calculate dependency and independence indices for each of the sub-criteria and ultimately compute the utility benchmark according to Eq. (37) for each supplier.

$$D_i = \sum_{j=1}^{j} \sum_{k=-1}^{k} P_j A_{kj}^D A_{kj}^l S_{ikj} , \tag{37}$$

where P_j is the relative weight of the criterion j. A_{kj}^D corresponds to the weight the relative importance of the sub-criteria k of the j[th] main criterion for its dependence. A_{kj}^l represents the relative importance of the sub criteria j of the criterion j for independence. S_{1kj} denotes the relative effect of the first supplier on the sub-criterion k in the supplier selection network. S_{2kj} denotes relative effect of second supplier on the sub-criterion k in the supplier selection network. Likewise, S_{3kj} denotes the relative effect of third supplier on the sub-criterion k. The utility of suppliers is a criterion for ranking them in terms of their eligibility for assignment of orders. Table 18 presents a method for calculating the relative importance of the criteria (P_j) as well as the pair-wise comparison matrix of suppliers in relation to each of the sub-criteria. The information in this table relates to the convergent large matrix of pairwise comparisons of benchmarks for the calculation of independence indices.

Table 18
Calculation of the utility index for suppliers

		P_j	A_{kj}^D	A_{kj}^l	S_{1kj}	S_{2kj}	S_{3kj}	D_1	D_2	D_3
C	PC	0.1804	0.4256	0.356482	0.4256	0.2872	0.2872	0.011649	0.007861	0.007861
	LC	0.1804	0.2872	0.333344	0.3333	0.4851	0.1816	0.005756	0.008378	0.003136
	DO	0.1804	0.2872	0.310175	0.241	0.3795	0.3795	0.003873	0.006099	0.006099
Q	QA	0.2665	0.5132	-*	0.4256	0.2872	0.2872	0.029104	0.01964	0.01964
	RR	0.2665	0.4868	-*	0.3795	0.241	0.3795	0.024617	0.015633	0.024617
D	DT	0.1163	0.248	0.283462	0.354	0.282	0.354	0.002894	0.002306	0.002894
	FOR	0.1163	0.4074	0.339627	0.2967	0.4765	0.2268	0.004774	0.007668	0.00365
	F	0.1163	0.3446	0.376912	0.2967	0.4765	0.2268	0.004482	0.007198	0.003426
T	TL	0.1804	0.3795	0.359809	0.241	0.3795	0.3795	0.005937	0.009348	0.009348
	RDC	0.1804	0.3795	0.39486	0.241	0.3795	0.3795	0.006515	0.010259	0.010259
	DC	0.1804	0.241	0.245332	0.4256	0.2872	0.2872	0.00454	0.003063	0.003063
EC	PP	0.2565	0.2768	0.231242	0.1816	0.4851	0.3333	0.002982	0.007964	0.005472
	RC	0.2565	0.1974	0.266875	0.3795	0.241	0.3795	0.005128	0.003257	0.005128
	EMS	0.2565	0.3	0.268262	0.4256	0.2872	0.2872	0.008786	0.005929	0.005929
	ED	0.2565	0.2258	0.233622	0.5	0.3139	0.1861	0.006765	0.004247	0.002518
							ΣD_i	0.127801	0.118848	0.113039
							D_i	0.35531	0.33042	0.31427

*Given the fact that the number of sub-criteria of the quality criterion is two, the independence index calculation does not matter to this case.

As mentioned earlier, in assigning orders to suppliers, two objective functions; (1) minimize total costs and (2) maximizing the value of purchases using utility indicators; are considered. The cost function includes the total cost of purchasing items, the order cost, the late payment, quality, and shipping costs. In the basic model, the values $Z_j^{max}(x)$ and $Z_j^{min}(x)$ were defined as the maximum and minimum values of the j^{th} target function. According to computational technique explained earlier, the first objective function is minimized subject to the set of constraints which gives the lower-bound (LB) of the objective value. In the same way, the first objective function ($\mathbf{F_1(X, Y)}$) is maximized using the same set of constraints to achieve the upper-bound (UB). This method continues for the second objective function ($F_2(X)$) to obtain the lower and upper bound of the objective functions. In order to implement the main steps of the optimization model under uncertainty conditions, it is necessary to solve each of the target functions separately in the definitive conditions. Thus $f_1^{min}(x_1^*)$ and $f_2^{max}(x_2^*)$ are obtained chronologically. In Table 20, the values of the target functions are solved individually. Solving the optimization model has been done with the application of GAMS 24.2 software.

Table 19
Independence index for sub-criteria of the supplier selection model

	PC	LC	DO	DT	FOR	F	TL	RDC	DC	PP	RC	EMS	ED
PC	0.356	0.356	0.356	0	0	0	0	0	0	0	0	0	0
LC	0.333	0.333	0.333	0	0	0	0	0	0	0	0	0	0
DO	0.310	0.310	0.310	0	0	0	0	0	0	0	0	0	0
DT	0	0	0	0.283	0.283	0.283	0	0	0	0	0	0	0
FOR	0	0	0	0.339	0.339	0.339	0	0	0	0	0	0	0
F	0	0	0	0.376	0.376	0.376	0	0	0	0	0	0	0
TL	0	0	0	0	0	0	0.360	0.360	0.360	0	0	0	0
RDC	0	0	0	0	0	0	0.393	0.393	0.393	0	0	0	0
DC	0	0	0	0	0	0	0.245	0.245	0.245	0	0	0	0
PP	0	0	0	0	0	0	0	0	0	0.231	0.231	0.231	0.231
RC	0	0	0	0	0	0	0	0	0	0.266	0.266	0.266	0.266
EMS	0	0	0	0	0	0	0	0	0	0.268	0.268	0.268	0.268
ED	0	0	0	0	0	0	0	0	0	0.233	0.233	0.233	0.233

Table 20
The maximum and minimum of target functions are single-objective

Model	$F_1(X,Y)$	$F_2(X)$
Cost minimization	6.60E+10	92810
Maximum Purchase Value	1.28E+11	168180

In Zimmermann approach, the weights for membership functions are measured equally. As mentioned earlier, λ is defined as the overall membership function for all the objective functions and the constraints. Accordingly, λ is maximized to obtain the solution of order allocation. By solving the fuzzy multi-objective optimization model, the calculated value is optimized for λ and it can be said that the multi-objective problem has been achieved by a nondominated solution. The solutions of Zimmermann approach are summarized in Table 21. The order allocated to each supplier in different periods are given in this table. The overall membership function is calculated as 0.275.

Table 21
Values of decision variables in a multi-objective fuzzy model

i=1	X	Y	i=2	X	Y	i=3	X	Y	λ
t=1	20174	1	t=1	0	0	t=1	27624	1	0.275
t=2	15176	1	t=2	0	0	t=2	22701	1	
t=3	20174	1	t=3	2174	1	t=3	2174	1	
t=4	2174	1	t=4	31362	1	t=4	0	0	
t=5	14736	1	t=5	8857	1	t=5	0	0	
t=6	20174	1	t=6	16026	1	t=6	0	0	

6. Conclusion remarks

In today's business, supplier selection is highly influenced by external factors and uncertainty affecting the demand and capacity of the supplier. Along with the growing global concern in supply chains about the environmental issues such as green production and sustainability, manufacturing companies have chosen to select green suppliers. The aim of green supplier selection is to evaluate suppliers with the highest potential for meeting a both environmental and firm's requirements. In the present green supplier selection model, an integrated approach of fuzzy-ANP and fuzzy multi-objective linear programming were proposed. Using the Fuzzy ANP model, an incomplete fuzzy linguistic approach was used to calculate the importance of each supplier for a manufacturing organization in a green supply chain. The main and the sub-criteria were compared to the opinions of the experts. Finally, weights were determined. After calculating the weight of each supplier, a fuzzy linear programming model was developed for order assignment, in which two functions of the target cost of purchase and purchase value were optimized simultaneously. In this model, the demand and the capacity of suppliers were considered as uncertain variables. Therefore, a fuzzy multi-objective linear programming model was used to solve it and the demand for each supplier was determined.

In order to validate the proposed approach, a case study of the automobile industry was conducted. The outputs of this case study afford practical insights for supply chain managers and research professionals. According to the results of this article, the companies can establish a systematic approach for simultaneous selection and assessment of green suppliers as well as the optimal allocation of order quantities to each supplier. Such a sustainable supplier selection model with the incomplete preferences has practical applications in supply chain management. The integrated supplier evaluation and order allocation model resulted in higher market share increasing product, cost reduction, increased the perceived quality, and improves the sustainability in the supply chain. The ANP model provides the more realistic suppliers' evaluation results against the existing methods. Thus, the proposed multi-criteria decision analysis model support the decision made by managers to minimize the risk of selecting disqualified suppliers against a set of qualitative and quantitative criteria.

As accounts for future research, randomized distributions of demand and capacity in each period can be captured by extending the basic model to a stochastic programming formulation. Furthermore, a variety of discounts can be considered, so that the original model is closer to real-world issues. For example, one can assume that each supplier is willing to reduce the price of each unit for a specified amount of purchase.

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References

Azar, A., Hemmatinezhad, M., & Kasbakhi, E. A. (2015). Supplier segmentation using fuzzy preference relations based AHP (Case study: Fouman Shimi). *Journal of Current Research in Science, 3*(6), 1.

Beheshtinia, M., & Nemati-Abozar, V. (2017). A novel hybrid fuzzy multi-criteria decision-making model for supplier selection problem (A case study in advertising industry). *Journal of Industrial and Systems Engineering, 9*(4), 65-79.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy sets and systems, 17*(3), 233-247.

Buckley, J. J., Feuring, T., & Hayashi, Y. (2001). Fuzzy hierarchical analysis revisited. *European Journal of Operational Research, 129*(1), 48-64.

Büyüközkan, G., & Göçer, F. (2017). Application of a new combined intuitionistic fuzzy MCDM approach based on axiomatic design methodology for the supplier selection problem. *Applied Soft Computing, 52*, 1222-1238.

Chai, J., Liu, J. N., & Ngai, E. W. (2013). Application of decision-making techniques in supplier selection: A systematic review of literature. *Expert Systems with Applications, 40*(10), 3872-3885.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research, 95*(3), 649-655.

Chen, C. C., Tseng, M. L., Lin, Y. H., & Lin, Z. S. (2010, December). Implementation of green supply chain management in uncertainty. *In Industrial Engineering and Engineering Management (IEEM), 2010 IEEE International Conference on (pp. 260-264). IEEE*.

Degraeve, Z., & Roodhooft, F. (1999). Effectively selecting suppliers using total cost of ownership. *Journal of Supply Chain Management, 35*(4), 5-10.

Demirtas, E. A., & Üstün, Ö. (2008). An integrated multi-objective decision making process for supplier selection and order allocation. *Omega, 36*(1), 76-90.

Dickson, G. W. (1996). An analysis of vendor selection systems and decisions. *Journal of Purchasing, 2*(1), 5-17.

Fahimnia, B., Sarkis, J., & Davarzani, H. (2015). Green supply chain management: A review and bibliometric analysis. *International Journal of Production Economics, 162*, 101-114.

Foroozesh, N., Tavakkoli-Moghaddam, R., & Mousavi, S. M. (2017). Resilient supplier selection in a supply chain by a new interval-valued fuzzy group decision model based on possibilistic statistical concepts. *Journal of Industrial and Systems Engineering, 10*(2), 113-133.

Govindan, K., Rajendran, S., Sarkis, J., & Murugesan, P. (2015). Multi criteria decision making approaches for green supplier evaluation and selection: a literature review. *Journal of Cleaner Production, 98,* 66-83.

Humphreys, P., McIvor, R., & Chan, F. (2003). Using case-based reasoning to evaluate supplier environmental management performance. *Expert Systems with Applications, 25*(2), 141-153.

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

Kuo, R. J., & Lin, Y. J. (2012). Supplier selection using analytic network process and data envelopment analysis. *International Journal of Production Research, 50*(11), 2852-2863.

Kuo, R. J., Wang, Y. C., & Tien, F. C. (2010). Integration of artificial neural network and MADA methods for green supplier selection. *Journal of cleaner production, 18*(12), 1161-1170.

Li, X., & Zhao, C. (2009, October). Selection of suppliers of vehicle components based on green supply chain. In Industrial Engineering and Engineering Management, 2009. *IE&EM'09. 16th International Conference on (pp. 1588-1591). IEEE.*

Prasad, K., Subbaiah, K., & Prasad, M. (2017). Supplier evaluation and selection through DEA-AHP-GRA integrated approach-A case study. *Uncertain Supply Chain Management, 5*(4), 369-382.

Qin, J., Liu, X., & Pedrycz, W. (2017). An extended TODIM multi-criteria group decision making method for green supplier selection in interval type-2 fuzzy environment. *European Journal of Operational Research, 258*(2), 626-638.

Sivrikaya, B. T., Kaya, A., Dursun, M., & Çebi, F. (2015). Fuzzy AHP–goal programming approach for a supplier selection problem. *Research in Logistics & Production, 5*(3), 271-285.

Stadtler, H. (2015). *Supply chain management: An overview. In Supply chain management and advanced planning (pp. 3-28)*. Springer Berlin Heidelberg.

Thongchattu, C., & Siripokapirom, S. (2010, August). Notice of retraction green supplier selection consensus by neural network. *In Mechanical and Electronics Engineering (ICMEE), 2010 2nd International Conference on (Vol. 2, pp. V2-313). IEEE*.

Weber, C. A., Current, J. R., & Benton, W. C. (1991). Vendor selection criteria and methods. *European Journal of Operational Research, 50*(1), 2-18.

Wen, U. P., & Chi, J. M. (2010, October). Developing green supplier selection procedure: a DEA approach. *In Industrial Engineering and Engineering Management (IE&EM), 2010 IEEE 17Th International Conference on (pp. 70-74). IEEE*.

Yan, G. E. (2009, May). Research on green suppliers' evaluation based on AHP & genetic algorithm. *In 2009 International Conference on Signal Processing Systems (pp. 615-619). IEEE*.

Zimmermann, H. J. (1978). Fuzzy programming and linear programming with several objective functions. *Fuzzy Sets and Systems*, *1*(1), 45-55.