Green Supplier Selection Based on Improved Intuitionistic Fuzzy TOPSIS Model

Mei Li[1, 2]

[1]School of Management, Harbin Institute of Technology, Harbin 150001, Heilongjiang, China
[2]School of Logistics Management and Engineering, Guangxi Teachers Education University, Nanning 530001, Guangxi, China

Chong Wu

School of Management, Harbin Institute of Technology, Harbin 150001, Heilongjiang, China

Abstract
Green supplier selection is an important part of green supply chain management. To improve the validity and reliability of green supplier selection, this paper constructed a model based on the improved intuitionistic fuzzy TOPSIS. Firstly, the concepts of intuitionistic fuzzy set and intuitionistic fuzzy number were given, and a series of algorithms and aggregation operators were defined; on the basis of considering hesitation degree, a new improvement was made on the existing intuitionistic fuzzy set measure. Then, this paper picked out several evaluation indexes based on the existing literatures and the development characteristics of the logistics industry, built an evaluation index system to meet the enterprise demand, meanwhile, extended the traditional TOPSIS and constructed green supplier selection model based on intuitionistic fuzzy TOPSIS theory. Finally, we proved the decision-making model was easy to operate and effective by an example. The result shows the model can effectively solve the problem of supplier selection under the uncertainty condition. The sensitivity training analysis result carried out by perturbation simulation to the evaluation index weight also shows that the improved model has good stability.
Key words: GREEN SUPPLIER SELECTION, EVALUATION INDEX SYSTEM, INTUITIONISTIC FUZZY SET, INFORMATION ENTROPY, TOPSIS

1. Introduction

Green supply chain management includes many parts, such as green product design, green supplier evaluation, green production, green packaging and transportation, green marketing and waste recycling, etc. As the green supplier part locates the upstream side of the whole supply chain, its function in saving cost and environmental protection can be passed to the downstream side through the supply chain, so as to improve the whole supply chain compatibility with the environment, so green supplier selection is the key to construct a green supply chain [1]. Comprehensive and objective optimum selection and establishing strategic alliance partnerships with high-quality suppliers can improve the operational efficiency of the green supply chain.

At present, a large number of studies carried out by scholars are mainly in two aspects, one is about to develop green supplier selection criteria and guidelines, the other is to construct the green supplier selection method and model. In 1966, Dickson [2] analyzed and arranged 23 criteria for supplier evaluation, and sort them by importance through the way of questionnaire survey. The top 3 of the criteria were the quality, delivery time and history performance. After that many scholars carried out a lot of research on the problem of supplier selection. In 1991, Weber et al. [3] analyzed and studied Dickson's research results on supplier evaluation criteria. He selected 74 related academic papers published between 1967 and 1990 and found the price, delivery time, quality and ability had very important effect on supplier selection decision. Beamon [4] emphasized environmental factors should be seriously considered in the supply chain model, and put forward more reasonable supply chain design model. He also proposed the concept of green supply chain and some new business indicators of green supply chain management including MRR (material recovery rate), CRR (core return rate), Ratio of virgin to recycled resources and eco-efficiency etc. Govindan et al. [5] carried on further analysis on 62 articles about green supplier selection research, made a comprehensive description about the advantages and disadvantages of multiple-attribute decision making method, and summarized the evaluation criteria with high attention. The research on green supplier selection method and model are both focused on fuzzy inference method [6-7], knowledge based system method [8-9], rough set theory method [10], the hybrid method [11-12] and so on.

So far, the research on evaluation index system and selection method of the green supplier has made substantial progress. Evaluation index is no longer limited to several mandatory indexes such as the price, delivery time, and pays more attention to the soft power of the green supplier such as sustainable development. Research has gradually become diversified, comprehensive and systematic. Green logistics supplier selection method research has experienced the periods of quantitative analysis, qualitative analysis and their combination. It is no longer limited to a single evaluation method, which makes the results more credible. However, there are still some shortcomings in current supplier evaluation system and decision model, which are mainly manifested in the following two aspects:

(1) Logistics supplier selection method doesn't take the change possibility of decision-makers' subjective evaluation into account. In fact in the green supplier selection process, quantitative data and qualitative data are usually need to be dealt with at the same time and even the effects of uncertain data information on decision making because the selection criteria and attributes can't be quantitative and there is some influence from decision-makers' subjective factors. At present, a lot of research scholars have turned to the uncertainty field using rough set or fuzzy set theory to deal with the impact of uncertainty information on decision making. However, the rough set theory requires the discrete data with large samples and strong statistical rules, so the calculation is large and it's easy to fail to extract the decision rules. Fuzzy set theory deals with the vagueness by membership function, takes the compliance of the actual situation of logistics providers to evaluate with the enterprises expected value into account, but without considering the possibility of uncertainty and change that is produced by decision-makers' subjective evaluation, so it need to be further improved.

(2) The evaluation index weights of the green supplier under incomplete information can't be treated objectively and reasonably. In practice, many factors such as diversification of user needs and shortened product life cycle often change and enterprises need to respond quickly, which makes enterprise decision often made without complete information. How to obtain scientific and reasonable attribute weights in the case of incomplete information will directly affect the rationality of logistics supplier decision results. The existing methods for solving the weights problem are not enough to deal with incomplete information, but the related research isn't very much and still faces many challenges.

In this paper, we studied the problem

of green supplier selection based on the improved intuitionistic fuzzy TOPSIS theory. Intuitionistic fuzzy theory can not only describe the compliance and difference of the green supplier actual performance with enterprise expectations, but also can describe the possibility of the decision-makers' neutral and hesitant attitude, and make a more scientific evaluation from two aspects of logistics supplier actual performance. This paper related the importance of each index with the uncertainty and introduced entropy weight method to determine the weight, which makes the application convenient and decision-makers can use the evaluation information directly to make decisions. Thus, the decision is more scientific, objective and easy to operate.

2. Improved intuitionistic fuzzy TOPSIS decision model

2.1 The basic theory of intuitionistic fuzzy sets

Intuitionistic fuzzy set is an extension of Atanassov [13-15] to Zadeh [16] traditional fuzzy set theory and it can deal with fuzzy information better. The intuitionistic fuzzy set is very effective in the application of the evaluation problem and it can be used to describe the fuzzy nature of information, so that the evaluation of the uncertainty information is more expressive.

Definition 1 [13] Assume X is a non-empty set and the intuitionistic fuzzy set A on the domain X can be noted as

$$A = \left\{ \left\langle x, \mu_A(x), \nu_A(x) \right\rangle \middle| x \in X \right\} \quad (1)$$

$\mu_A(x)$ and $\nu_A(x)$ are respectively degrees of membership and non-membership of element x belonged to A on X, i.e. $\mu_A : X \to [0,1]$, $x \in X \to \mu_A(x) \in [0,1]$, $\nu_A : X \to [0,1]$, $x \in X \to \nu_A(x) \in [0,1]$, $0 \le \mu_A(x) + \nu_A(x) \le 1$; then $\pi_A = 1 - \mu_A(x) - \nu_A(x)$ is the degree of hesitation or uncertainty of element x belonged to A on X. Obviously, for any $x \in X$, $0 \le \pi_A(x) \le 1$. Intuitionistic fuzzy integration operator is defined as follows:

Definition 2[17] Assume $\alpha_j = \left(\mu_{\alpha_j}, \nu_{\alpha_j}\right)$ $(j = 1,2,\cdots,n)$ are intuitionistic fuzzy numbers and IFWA: $\Theta^n \to \Theta$, if

$$IFWA_{\varpi}(\alpha_1, \alpha_2, \cdots \alpha_n) = \omega_1\alpha_1 \oplus \omega_2\alpha_2 \oplus \cdots \oplus \omega_n\alpha_n \quad (2)$$

Then IFWA is an intuitionistic fuzzy weighted average operator, and $\omega = (\omega_1, \ \omega_2, \cdots, \omega_n)^T$ is the weighted vector of $\alpha_j \ (j = 1,2,\cdots,n)$, $\omega_j \in [0,1]$ $(j = 1,2,\cdots,n)$, $\sum_{j=1}^{n} \omega_j = 1$.

Theorem 1[17] Assume $\alpha_j = \left(\mu_{\alpha_j}, \nu_{\alpha_j}\right)$ $(j = 1,2,\cdots,n)$, then

$$IFWA_{\omega}(\alpha_1, \alpha_2, \cdots, \alpha_n) = (1 - \prod_{j=1}^{n} (1 - \mu_{\alpha_i})^{\omega_i}, \prod_{j=1}^{n} \nu_{\alpha_j}{}^{\omega_i}) \quad (3)$$

And the values integrated from IFWA operators are also intuitionistic fuzzy numbers.

If $\omega = (\frac{1}{n}, \frac{1}{n}, \cdots, \frac{1}{n})^T$, then intuitionistic fuzzy weighted average operator (IFWA) will be reduced to intuitionistic fuzzy average operator (IFA):

$$IFA_{1/n}(\alpha_1, \alpha_2, \cdots, \alpha_n) = (1 - \prod_{j=1}^{n} (1 - \mu_{\alpha_i})^{\frac{1}{n}}, \prod_{j=1} \nu_{\alpha_j}{}^{\frac{1}{n}}) \quad (4)$$

2.2 Score function and its improvement

Assume $\alpha = (\mu_\alpha, \nu_\alpha)$, we can evaluate it by score function:

$$s(\alpha) = \mu_\alpha - \nu_\alpha \quad (5)$$

$s(\alpha)$ is the score value of α, $s(\alpha) \in [-1,1]$. We can see from eq.(5), the greater $s(\alpha)$ value, the greater α value. For better evaluation of intuitionistic fuzzy number, Hong and Choi [18] proposed the concept of exact function, i.e.

$$h(\alpha) = \mu_\alpha + \nu_\alpha \quad (6)$$

$h(\alpha)$ is the accuracy of α. The greater $h(\alpha)$ value, the greater the accuracy of the intuitionistic fuzzy number α.

But traditional score function doesn't take the hesitation effect into account, obviously incomprehensive. Thus, in a complicated environment, traditional score function in some cases can't compare the value of the intuitionistic fuzzy numbers, moreover, the result often doesn't fit the actual situation. The traditional score function need to be improved.

As a result, a lot of scholars improved the traditional score function by considering the approval, the disapproval and the neutral at the same time. In 2006, Wang et al. [19] proposed a score function, i.e.

$$s(\alpha)=\mu_\alpha-\nu_\alpha+\frac{1-\mu_\alpha-\nu_\alpha}{2} \quad (7)$$

μ_α, ν_α and $1-\mu_\alpha-\nu_\alpha$ represent the proportion values of the approval, the disapproval and the neutral seperately. The greater the score function value, the better the alternative satisfies the decision-makers' need, but the method just simply considers half of the neutral group will approve, which is inconsistent with the actual situation.

In 2007, Liu and Wang [20] separated the neutral group into n groups and put forward the score function as follows:

$$s_n(\alpha)=\mu_\alpha+a\pi_\alpha+a(1-a-b)\pi_\alpha+\cdots+a(1-a-b)^{n-1}\pi_\alpha \quad (8)$$

$a,b\in[0,1]$, $0\le a+b\le 1$.

But the values of a and b in eq. (8) still can't be determined reasonably, which restricts its application in practice.

To sum up, we can find these score functions are based on a single-time-vote by the neutral, however, they can't make a final decision in a short period of time or in a lump sum. The given results are often uncertain and inaccurate. This paper considered the effect of the neutral on decision-making and assumed that the neutral can make a relatively stable judgment through n voting, so we propose the improved score function as follows:

$$s_n'(\alpha)=\mu_\alpha-\nu_\alpha+\pi_\alpha+(\mu_\alpha-\nu_\alpha)\pi_\alpha^{\ 2}+\cdots+(\mu_\alpha-\nu_\alpha)\pi_\alpha^{\ n} \quad (9)$$

From eq. (9) we know, in the n voting model, the proportions of proponents, opponents and the neutral are noted as μ_α, ν_α and π_α. Among the neutral π_α, the group tending to approve is noted as $\mu_\alpha\pi_\alpha$, the group tending to disapprove is noted as $\nu_\alpha\pi_\alpha$ and the group tending to be neutral is noted as $\pi_\alpha\pi_\alpha$ and so on, through further analogy, the proportions who tend to approve in the neutral are $\mu_\alpha\pi_\alpha$, $\mu_\alpha\pi_\alpha^{\ 2}$, $\cdots$, $\mu_\alpha\pi_\alpha^{\ n}$, the proportions who tend to disapprove are $\nu_\alpha\pi_\alpha$, $\nu_\alpha\pi_\alpha^{\ 2}$, $\cdots$, $\nu_\alpha\pi_\alpha^{\ n}$, and the differences will be $(\mu_\alpha-\nu_\alpha)\pi_\alpha$, $(\mu_\alpha-\nu_\alpha)\pi_\alpha^{\ 2}$, $\cdots$, $(\mu_\alpha-\nu_\alpha)\pi_\alpha^n$, which means the voting will be highly consistent with the general opinion of the decision-making group.

We can get improved score function after taking limit of eq. (9):

$$s_n'(\alpha)=\mu_\alpha-\nu_\alpha+\frac{\pi_\alpha}{1-\pi_\alpha}(\mu_\alpha-\nu_\alpha)=\frac{1}{1-\pi_\alpha}(\mu_\alpha-\nu_\alpha) \quad (10)$$

2.3 Similarity and its improvement

Definition 3 [21] Given mapping $S: IFS(X)\times IFS(X)\to[0,1]$, if

(1) $0\le S(A,B)\le 1$;

(2) If $A=B$, then $S(A,B)=1$;

(3) $S(A,B)=S(B,A)$;

(4) If $A\subseteq B\subseteq C$, then $S(A,C)\le S(A,B)$, $S(A,C)\le S(B,C)$.

Then $S(A,B)$ is called the similarity of intuitionistic fuzzy sets A and B.

Intuitionistic fuzzy set similarity can reflect the proximity of two intuitionistic fuzzy sets. The greater the similarity, the greater the proximity. The most classic one was proposed by Xu [17] based on geometry distance as follows in 2007:

Definition 4 A finite set $X=\{x_1,x_2,\cdots,x_n\}$, the measure formula to calculate the similarity of intuitionistic fuzzy set A and B is

$$S(A,B)=1-\left[\frac{1}{2n}\sum_{i=1}^{n}\left(\left|\mu_A(x_i)-\mu_B(x_i)\right|^q+\left|\pi_A(x_i)-\pi_B(x_i)\right|^q+\left|\nu_A(x_i)-\nu_B(x_i)\right|^q\right)\right]^{1/q} \quad (11)$$

q is a distance parameter and $q>0$. We can select a appropriate value for q according to the actual need.

Besides, Wei et al. [22] put forward a new formula for intuitionistic fuzzy set similarity based on the fuzzy entropy theory:

$$S(A,B)=\frac{1}{n}\sum_{i=1}^{n}\frac{1-\min\{\mu_i,\nu_i\}}{1+\max\{\mu_i,\nu_i\}} \quad (12)$$

$\mu_i=\left|\mu_A(x_i)-\mu_B(x_i)\right|$, $\nu_i=\left|\nu_A(x_i)-\nu_B(x_i)\right|$

However, the existing similarity measure formula is easy to cause counterintuitive problem in some cases. Sometimes it's impossible to distinguish which two intuitionistic fuzzy sets are more similar. Thus, we give the similarity measure formula considering the subsequent effect from the voting result by the neutral.

Definition 5 $X=\{x_1, x_2, \cdots, x_n\}$, the similarity measure formula for intuitionistic fuzzy sets A and B is:

$$S(A,B)=1-\frac{1}{n}\left[\sum_{i=1}^{n}\left(\left|\mu_A^{'}(x_i)-\mu_B^{'}(x_i)\right|+\left|\nu_A^{'}(x_i)-\nu_B^{'}(x_i)\right|\right)\right]$$

(13)

$$\mu_A^{'}(x_i)=\mu_A(x_i)+\frac{1+\mu_A(x_i)-\nu_A(x_i)}{2}\pi_A(x_i)$$

,

$$\mu_B^{'}(x_i)=\mu_B(x_i)+\frac{1+\mu_B(x_i)-\nu_B(x_i)}{2}\pi_B(x_i)$$

$\frac{1+\mu_A(x_i)-\nu_A(x_i)}{2}$ means we first think the persons who casting a positive vote are as many as who cast a negative vote, then use the half of the difference $\frac{\mu_\alpha-\nu_\alpha}{2}$ between positive votes and negative votes to amend the weight value.

Certification Now we certify that the above formulas satisfy 4 axioms in definition 5.

For $\forall x_i \in X$,

$$0\le\frac{1}{n}\left[\sum_{i=1}^{n}\left(\left|\mu_A^{'}(x_i)-\mu_B^{'}(x_i)\right|+\left|\nu_A^{'}(x_i)-\nu_B^{'}(x_i)\right|\right)\right]\le 1$$

, so $0\le S(A,B)\le 1$.

(2)If $A=B$, then $\mu_A(x_i)=\mu_B(x_i)$, $\nu_A(x_i)=\nu_B(x_i)$, then $S(A,B)=1$.

(3) From eq. (13), there is $S(A,B)=S(B,A)$.

(4) $S(A,C)-S(A,B)=$

$$\frac{1}{n}\left[\sum_{i=1}^{n}\left(\left|\mu_A^{'}(x_i)-\mu_B^{'}(x_i)\right|+\left|\nu_A^{'}(x_i)-\nu_B^{'}(x_i)\right|\right)\right]$$

$-$

$$\frac{1}{n}\left[\sum_{i=1}^{n}\left(\left|\mu_A^{'}(x_i)-\mu_C^{'}(x_i)\right|+\left|\nu_A^{'}(x_i)-\nu_C^{'}(x_i)\right|\right)\right]$$

$=-$

$$\frac{1}{n}\left[\sum_{i=1}^{n}\left(\left|\mu_B^{'}(x_i)-\mu_C^{'}(x_i)\right|+\left|\nu_B^{'}(x_i)-\nu_C^{'}(x_i)\right|\right)\right]$$

From $A\subseteq B\subseteq C$, $S(A,C)-S(A,B)\le 0$, then $S(A,C)\le S(A,B)$.The same can be proved, $S(A,C)\le S(B,C)$.

Besides, if $\omega=(\omega_1,\ \omega_2,\cdots,\ \omega_n)^T$ is a weight vector, ω_i is the weight of each attribute $X_i\in X$, then the weight similarity formula of intuitionistic fuzzy sets A and B is

$$S(A,B)=1-\left[\sum_{i=1}^{n}\omega_i\left(\left|\mu_A^{'}(x_i)-\mu_B^{'}(x_i)\right|+\left|\nu_A^{'}(x_i)-\nu_B^{'}(x_i)\right|\right)\right]$$

(14)

2.4 The basic principle of TOPSIS

Traditional TOPSIS is an evaluation method to solve multiple attribute decision making problems proposed by Hwang and other scholars and has been widely applied in many fields. The detailed steps are as follows:

Step 1 Construct decision-making matrix A that has m evaluation objects and n attribute indexes. x_{ij} is noted as the corresponding value of the j th $(\mathrm{j}=1,2,\cdots,\mathrm{n})$ attribute index of the i th $(i=1,2,\cdots,m)$ evaluation object.

$$A=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (15)$$

Step 2 Set up the normalized decision matrix R. In order to eliminate the difference between different attributes, normalize the decision matrix A and get $R=(r_{ij})_{m\times n}$.

$$r_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m}x_{ij}^2}} \quad (16)$$

Step 3 Establish weighted decision matrix Z.

$$Z=(z_{ij})_{m\times n}=w_j * r_{ij} \quad (17)$$

$i=1,2,\cdots,m$, $j=1,2,\cdots,n$. w_j is the weight of each attribute index and $w_j>0$.

Step 4 Determine positive ideal solution S^+ and negative ideal solution S^-,

$$S^+=\{s_1^+, s_2^+,\cdots, s_j^+,\cdots, s_n^+\}$$

(18)

$$S^-=\{s_1^-, s_2^-,\cdots, s_j^-,\cdots, s_n^-\} \quad (19)$$

$$s_j^+ = \begin{cases} \max\limits_i z_{ij}, & j \text{ as the benefit index}, \; j = 1,2,\cdots,n \\ \min\limits_i z_{ij}, & j \text{ as the cost index}, \; j = 1,2,\cdots,n \end{cases}$$

$$s_j^- = \begin{cases} \min\limits_i z_{ij}, & j \text{ as the benefit index}, \; j = 1,2,\cdots,n \\ \max\limits_i z_{ij}, & j \text{ as the cost index}, \; j = 1,2,\cdots,n \end{cases}$$

Step 5 Calculate the distance D_i^+ between the ith evaluation object and the positive ideal solution S^+, and the distance D_i^- between the ith evaluation object and the negative ideal solution S^-.

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(z_{ij} - s_j^+\right)^2} \quad (20)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(z_{ij} - s_j^-\right)^2} \quad (21)$$

Step 6 Calculate the relative closeness between each evaluation object.

$$C_i^* = \frac{D_i^-}{D_i^+ + D_i^-} \quad (22)$$

Sort C_i^* by relative closeness.

2.5 Green supplier selection model based on improved intuitionistic fuzzy TOPSIS

Suppose there are n green suppliers to be evaluated to constitute the alternative sets $A = \{A_1, A_2, \cdots, A_n\}$, evaluation index set is the attribute set $C = \{C_1, C_2, \cdots, C_m\}$, the weight vector of evaluation index is $\omega = (\omega_1, \omega_2, \cdots \omega_m)^T$, $\sum_{j=1}^{n}\omega_j = 1$, $\omega_j \in [0,1], (j = 1,2,\cdots,m)$. $\mu_{ij} \in [0,1]$ is noted as the degree that shows how alternative A_i satisfies attribute C_j, $\nu_{ij} \in [0,1]$ is noted as the degree that shows how alternative A_i dissatisfies attribute C_j, $0 \le \mu_{ij} + \nu_{ij} \le 1$. The evaluation of alternative $A_i (i = 1,2,\cdots,n)$ about attribute $C_j (j = 1,2,\cdots,m)$ can be noted by intuitionistic fuzzy number $d_{ij} = (\mu_{ij}, \nu_{ij})$. Thus, green supplier selection problem can be noted as decision matrix $D = (d_{ij})_{m\times n}$, as shown in table 1.

Table 1. Intuitionistic fuzzy decision matrix *D*.

	A_1	A_2	$\cdots$	A_n
C_1	(μ_{11}, ν_{11})	(μ_{12}, ν_{12})	$\cdots$	(μ_{1n}, ν_{1n})
C_2	(μ_{21}, ν_{21})	(μ_{22}, ν_{22})	$\cdots$	(μ_{2n}, ν_{2n})
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$
C_m	(μ_{m1}, ν_{m1})	(μ_{m2}, ν_{m2})	$\cdots$	(μ_{mn}, ν_{mn})

This paper started from collecting the relevant information of the green suppliers to be evaluated and the subjective evaluation information was given by the experts and aggregated into comprehensive attribute values, then determined each evaluation index weight by intuitionistic fuzzy entropy, finally applied the improved intuitionistic fuzzy TOPSIS to sort the green suppliers by comprehensive situation. The evaluation course is shown in Fig.1.

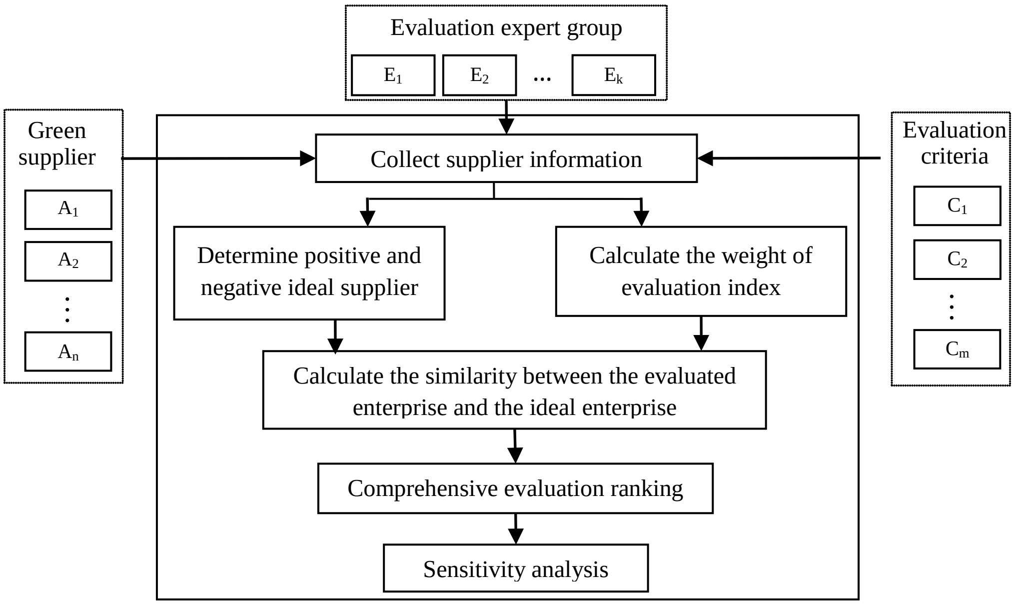

Figure 1. Green supplier selection process.

Here are the steps of green supplier selection model based on improved intuitionistic fuzzy TOPSIS.

Step 1 The evaluation group consists of k experts gives the intuitionistic fuzzy evaluation value of each supplier A_i about attribute C_j, and the evaluation value made by each expert can constitute the intuitionistic fuzzy matrix $D^{(k)} = (d_{ij}^{(k)})_{m \times n}$.

Step 2 Assuming the status of k evaluation experts is equal, $\omega = (\frac{1}{k}, \frac{1}{k}, \cdots, \frac{1}{k})^T$, then from eq. (4) we can get the attribute value $\overline{d_{ij}} = (\overline{\mu_{ij}}, \overline{\nu_{ij}})$ by aggregating the intuitionistic fuzzy information of green supplier A_i about attribute R_j.

Step 3 Determine the weight of each index in combination with intuitionistic fuzzy entropy. Let the intuitionistic fuzzy entropy of index j be

$$E_j = \frac{1}{m} \sum_{i=1}^{m} \frac{1 - \left|\overline{\mu_{ij}} - \overline{\nu_{ij}}\right| + \overline{\pi_{ij}}}{1 + \left|\overline{\mu_{ij}} - \overline{\nu_{ij}}\right| + \overline{\pi_{ij}}} \qquad (23)$$

So the greater intuitionistic fuzzy entropy of C_j, the greater the uncertainty, and the smaller the provided information quantity, thus, the less important in the evaluation and vice versa. As a result, the weight of index j is

$$\omega_j = \frac{1 - E_j}{\sum_{k=1}^{n} (1 - E_k)} \qquad (24)$$

Step 4 Determine the positive ideal green supplier A^+ and the negative ideal green supplier A^-.

$$A^+ = \{(\mu_1^+, \nu_1^+), (\mu_2^+, \nu_2^+), \cdots, (\mu_n^+, \nu_n^+)\} \qquad (25)$$

$$A^- = \{(\mu_1^-, \nu_1^-), (\mu_2^-, \nu_2^-), \cdots, (\mu_n^-, \nu_n^-)\} \qquad (26)$$

$$(u_j^+, \nu_j^+) = (\max_{1 \le i \le m}\{\overline{\mu_{ij}}\}, \min_{1 \le i \le m}\{\overline{\nu_{ij}}\}),$$

$$(u_j^-, \nu_j^-) = (\min_{1 \le i \le m}\{\overline{\mu_{ij}}\}, \max_{1 \le i \le m}\{\overline{\nu_{ij}}\}).$$

Step 5 Calculate the relative closeness of each green supplier A_i. First, calculate the closeness of green supplier A_i to the positive and to the negative green supplier separately noting by $S(A_i, A^+)$ and $S(A_i, A^-)$. Then calculate the relative closeness of green supplier A_i to A^+ and A^- separately.

$$S(A_i) = \frac{S(A_i, A^+)}{S(A_i, A^+) + S(A_i, A^-)},$$

$$i = 1, 2, \cdots, n \qquad (27)$$

Step 6 Sort green supplier A_i by $S(A_i)$, the greater $S(A_i)$ value, the better the comprehensive performance level of green suppliers.

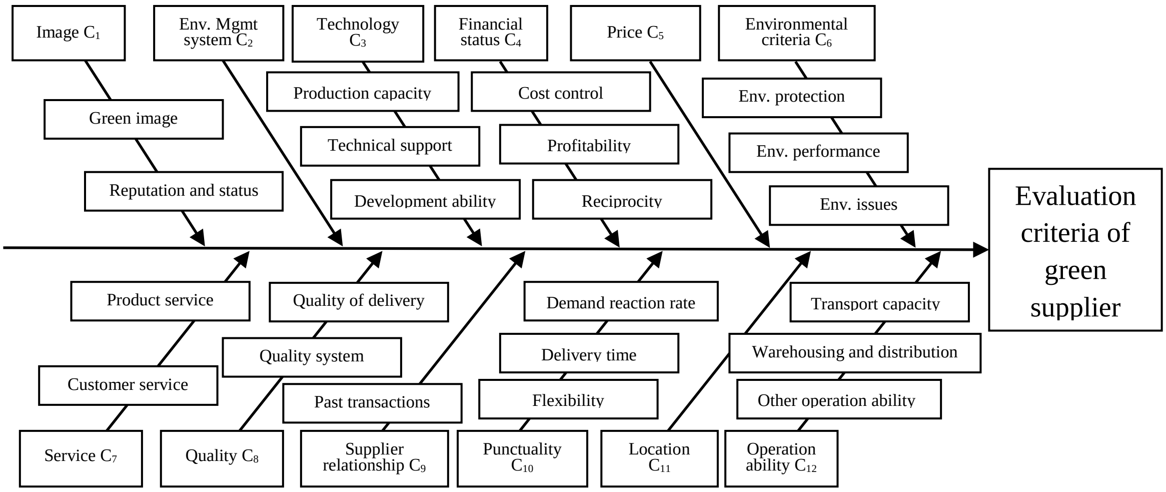

Figure 2. Evaluation criteria of green supplier

3. The green supplier selection empirical research

3.1 The construction of green supplier selection index system

Supplier selection is the basis for establishing and maintaining long-term cooperative relationship between enterprises and their suppliers. Generally speaking, the traditional supplier selection is a comprehensive analysis of the supplier evaluation index, such as product quality, product price, delivery time, delivery time stability and after-sales service. In addition, green supplier selection is put forward and considers the environmental health and safety as the primary factor. By selecting the suitable green supplier, and establishing close and long-term cooperation relations, enterprises can not only reduce costs, decrease inventory, improve cash flow, but also can satisfy the expectation of supply chain and consumers for friendly environment.

Through the summary of a large number of literatures, combination with the development of the green supply chain, and integration of expert opinions, we finally established 22 indexes and integrated them into 12 indexes$\left(C_1 \sim C_{12}\right)$. Due to the large number of index, in order to help experts score fast and accurately, we designed the fishbone diagram of green supplier selection evaluation index system.

3.2 Empirical process and results

Step 1 Evaluation experts give the intuitionistic fuzzy evaluation values of A_i about attribute C_j based on the performance of the green suppliers, which is shown in table 2 ~ table 5.

Table 2. Evaluation value of E_1

	A_1	A_2	A_3	A_4	A_5
C_1	(0.37,0.19)	(0.72,0.10)	(0.34,0.35)	(0.48,0.27)	(0.52,0.18)
C_2	(0.82,0.03)	(0.86,0.05)	(0.49,0.10)	(0.63,0.10)	(0.83,0.07)
C_3	(0.47,0.28)	(0.91,0.09)	(0.42,0.25)	(0.50,0.20)	(0.59,0.31)
C_4	(0.53,0.47)	(0.86,0.08)	(0.38,0.60)	(0.44,0.56)	(0.67,0.31)
C_5	(0.63,0.06)	(0.88,0.01)	(0.53,0.28)	(0.56,0.30)	(0.73,0.12)
C_6	(0.65,0.10)	(0.82,0.09)	(0.43,0.12)	(0.58,0.32)	(0.72,0.20)
C_7	(0.62,0.18)	(0.82,0.11)	(0.47,0.44)	(0.63,0.36)	(0.62,0.37)
C_8	(0.48,0.30)	(0.74,0.08)	(0.30,0.50)	(0.37,0.42)	(0.50,0.40)

C_9	(0.19,0.51)	(0.61,0.20)	(0.20,0.69)	(0.29,0.60)	(0.34,0.52)
C_{10}	(0.20,0.52)	(0.30,0.58)	(0.37,0.45)	(0.15,0.58)	(0.32,0.45)
C_{11}	(0.56,0.44)	(0.86,0.11)	(0.33,0.65)	(0.44,0.46)	(0.68,0.32)
C_{12}	(0.50,0.42)	(0.80,0.16)	(0.32,0.48)	(0.52,0.45)	(0.64,0.27)

Table 3. Evaluation value of E_2.

	A_1	A_2	A_3	A_4	A_5
C_1	(0.37,0.51)	(0.67,0.12)	(0.39,0.47)	(0.35,0.48)	(0.65,0.23)
C_2	(0.62,0.18)	(0.92,0.05)	(0.48,0.21)	(0.72,0.14)	(0.82,0.13)
C_3	(0.37,0.36)	(0.62,0.21)	(0.39,0.38)	(0.58,0.29)	(0.54,0.24)
C_4	(0.52,0.42)	(0.78,0.22)	(0.38,0.56)	(0.47,0.41)	(0.63,0.36)
C_5	(0.51,0.42)	(0.77,0.23)	(0.25,0.45)	(0.35,0.34)	(0.54,0.31)
C_6	(0.60,0.21)	(0.88,0.10)	(0.36,0.45)	(0.56,0.28)	(0.78,0.19)
C_7	(0.42,0.45)	(0.82,0.10)	(0.36,0.45)	(0.50,0.35)	(0.68,0.24)
C_8	(0.53,0.36)	(0.73,0.12)	(0.29,0.32)	(0.59,0.11)	(0.59,0.30)
C_9	(0.38,0.57)	(0.70,0.23)	(0.30,0.54)	(0.33,0.67)	(0.34,0.60)
C_{10}	(0.30,0.50)	(0.49,0.34)	(0.08,0.72)	(0.32,0.40)	(0.28,0.50)
C_{11}	(0.42,0.53)	(0.63,0.32)	(0.42,0.46)	(0.56,0.40)	(0.68,0.32)
C_{12}	(0.30,0.55)	(0.70,0.19)	(0.31,0.52)	(0.50,0.32)	(0.57,0.32)

Table 4. Evaluation value of E_3.

	A_1	A_2	A_3	A_4	A_5
C_1	(0.57,0.32)	(0.78,0.18)	(0.47,0.35)	(0.45,0.27)	(0.58,0.24)
C_2	(0.84,0.13)	(0.98,0.01)	(0.48,0.37)	(0.74,0.24)	(0.94,0.04)
C_3	(0.72,0.13)	(0.76,0.18)	(0.47,0.45)	(0.56,0.31)	(0.72,0.10)
C_4	(0.68,0.28)	(0.82,0.09)	(0.42,0.53)	(0.58,0.42)	(0.65,0.35)
C_5	(0.69,0.21)	(0.83,0.12)	(0.46,0.41)	(0.49,0.32)	(0.53,0.32)
C_6	(0.50,0.35)	(0.87,0.08)	(0.30,0.45)	(0.61,0.08)	(0.51,0.28)
C_7	(0.61,0.34)	(0.85,0.12)	(0.45,0.31)	(0.52,0.29)	(0.70,0.20)
C_8	(0.73,0.12)	(0.82,0.18)	(0.19,0.58)	(0.63,0.10)	(0.60,0.35)
C_9	(0.35,0.52)	(0.40,0.45)	(0.20,0.60)	(0.38,0.52)	(0.51,0.28)
C_{10}	(0.43,0.40)	(0.60,0.22)	(0.15,0.65)	(0.27,0.45)	(0.43,0.40)
C_{11}	(0.58,0.41)	(0.81,0.08)	(0.48,0.52)	(0.52,0.35)	(0.57,0.42)
C_{12}	(0.56,0.32)	(0.71,0.17)	(0.40,0.49)	(0.43,0.46)	(0.61,0.32)

Table 5. Evaluation value of E_4.

	A_1	A_2	A_3	A_4	A_5
C_1	(0.43,0.33)	(0.67,0.30)	(0.31,0.40)	(0.33,0.30)	(0.32,0.22)
C_2	(0.73,0.22)	(0.75,0.11)	(0.42,0.25)	(0.65,0.11)	(0.84,0.13)
C_3	(0.54,0.24)	(0.68,0.12)	(0.35,0.55)	(0.52,0.23)	(0.58,0.26)
C_4	(0.42,0.54)	(0.87,0.23)	(0.42,0.50)	(0.49,0.50)	(0.57,0.43)
C_5	(0.43,0.55)	(0.82,0.09)	(0.33,0.32)	(0.51,0.17)	(0.79,0.05)
C_6	(0.56,0.33)	(0.88,0.10)	(0.39,0.18)	(0.58,0.23)	(0.68,0.17)
C_7	(0.48,0.24)	(0.93,0.07)	(0.36,0.36)	(0.54,0.26)	(0.77,0.19)
C_8	(0.54,0.32)	(0.56,0.12)	(0.38,0.42)	(0.47,0.32)	(0.55,0.02)
C_9	(0.33,0.46)	(0.66,0.17)	(0.24,0.60)	(0.36,0.50)	(0.42,0.39)
C_{10}	(0.35,0.45)	(0.45,0.34)	(0.30,0.42)	(0.21,0.59)	(0.50,0.30)
C_{11}	(0.62,0.36)	(0.95,0.04)	(0.32,0.60)	(0.56,0.38)	(0.62,0.35)
C_{12}	(0.55,0.45)	(0.62,0.30)	(0.28,0.50)	(0.32,0.58)	(0.45,0.38)

Step 2 Integrate the intuitionistic fuzzy evaluation values given by the 4 evaluation experts whose status is the same with eq. (4).

Table 6. The comprehensive value of green supplier evaluation index

	A_1	A_2	A_3	A_4	A_5
C_1	(0.44,0.32)	(0.76,0.13)	(0.38,0.39)	(0.41,0.32)	(0.53,0.22)
C_2	(0.77,0.11)	(0.92,0.05)	(0.47,0.21)	(0.69,0.14)	(0.87,0.08)
C_3	(0.54,0.24)	(0.75,0.14)	(0.41,0.39)	(0.54,0.25)	(0.61,0.21)
C_4	(0.55,0.42)	(0.84,0.08)	(0.40,0.55)	(0.50,0.47)	(0.63,0.36)
C_5	(0.58,0.21)	(0.83,0.07)	(0.40,0.36)	(0.48,0.27)	(0.67,0.16)
C_6	(0.58,0.22)	(0.86,0.09)	(0.37,0.26)	(0.58,0.20)	(0.69,0.21)
C_7	(0.54,0.29)	(0.86,0.10)	(0.41,0.39)	(0.55,0.31)	(0.70,0.24)
C_8	(0.58,0.25)	(0.73,0.12)	(0.29,0.44)	(0.53,0.20)	(0.56,0.17)
C_9	(0.32,0.51)	(0.61,0.24)	(0.24,0.61)	(0.34,0.57)	(0.41,0.43)
C_{10}	(0.33,0.47)	(0.47,0.35)	(0.23,0.55)	(0.24,0.50)	(0.39,0.41)
C_{11}	(0.55,0.43)	(0.85,0.10)	(0.39,0.55)	(0.52,0.40)	(0.64,0.36)
C_{12}	(0.49,0.43)	(0.71,0.20)	(0.33,0.50)	(0.45,0.44)	(0.57,0.32)

Step 3 Determine the weights of each attribute C_j with eq. (23) and (24).

$$\omega = (0.060,0.144,0.085,0.073,0.093,0.106,0.091,0.092,0.068,0.048,0.081,0.057)^T$$

Step 4 Determine the positive and negative ideal manufacturing enterprises with eq. (25) and (26).

$$A^{+}=\{(0.76,0.13),(0.92,0.05),(0.75,0.14),(0.84,0.08),(0.83,0.07),(0.86,0.09),$$
$$(0.86,010),(0.73,0.12),(0.61,0.24),(0.47,0.35),(0.85,0.10),(0.71.0.20)\}$$
$$A^{-}=\{(0.38,0.39),(0.47,0.21),(0.41,0.39),(0.40,0.55),(0.40,0.36),(0.37,0.26),$$
$$(0.41,0.39),(0.29,0.44),(0.24,0.61),(0.23,0.55),(0.39,0.55),(0.33,0.50)\}$$

Step 5 Calculate the similarities $S(A_i, A^{+})$, $S(A_i, A^{-})$ between manufacturing enterprises A_i and A^{+}, A^{-} separately with eq. (27).

Table 7. Relative closeness degree of green supplier A_i

	$S(A_i, A^{+})$	$S(A_i, A^{-})$	$S(A_i)$
A_1	0.587	0.712	0.452
A_2	0.999	0.299	0.770
A_3	0.299	0.999	0.230
A_4	0.536	0.764	0.412
A_5	0.727	0.572	0.561

Step 6 Sort green supplier A_i by $S(A_i)$ value according to table 7.

$A_2 \succ A_5 \succ A_1 \succ A_4 \succ A_3$

So the optimum green supplier is A_2.

3.3 Sensitivity analysis

This paper weighted each evaluation index according to the original evaluation information made by the decision experts in the process of green supplier selection decision. When the weight changes, whether the sorting of the obtained potential logistics supplier changes and what happens, is the key to judge effectiveness of the model and implement quantitative decision-making. Through the sensitivity analysis to evaluation index weights, we can determine whether the change of each evaluation index weight will lead to the deviation of the final decision [23] or not, that is to judge the corresponding change in the sorting of the potential green suppliers after the small perturbation to the evaluation index weight in decision-making. The model was simulated by using the perturbation method.

Note the original weight of evaluation index C_i as $\omega_i (i=1,2,\cdots,m)$ and the perturbed weight as $\omega_i^{'}=\xi\omega_i$. As we need to make sure the weight is between $[0,1]$, the change of parameter ξ is between $[0,1/\omega_i]$. Because of the normalization of the weight the rest index weights will change accordingly after one of them changes, noting as $\omega_k^{'}=\rho_k\omega_k \ (k=1,2,\cdots,m,k\neq i)$.

Each weight after perturbed should satisfy $\omega_i^{'}+\sum_{k=1,k\neq i}^{m}\omega_k^{'}=1$, i.e. $\xi\omega_i+\sum_{k=1,k\neq i}^{m}\rho_k\omega_k=1$. Using linear equation solving tool, we can find out each index weight value after one of them being perturbed, and then sort the potential logistics supplier with intuitionistic fuzzy TOPSIS according to the green supplier selection model proposed in Section 2.5.

In the sensitivity analysis of this paper, we set $\xi=2,3,1/2,1/3$ successively, and perturbed 12 evaluation indexes in Fig. 2, which amounted to 48 experiments and we got the sensitivity analysis result shown in Fig. 3 and Fig. 4.

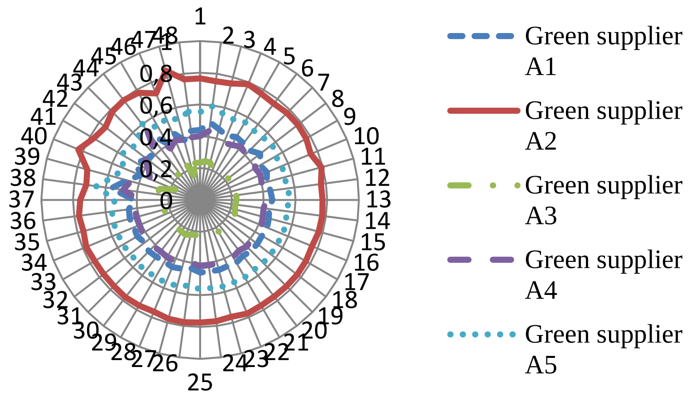

Figure 3. The sensitivity analysis result of green supplier relative closeness

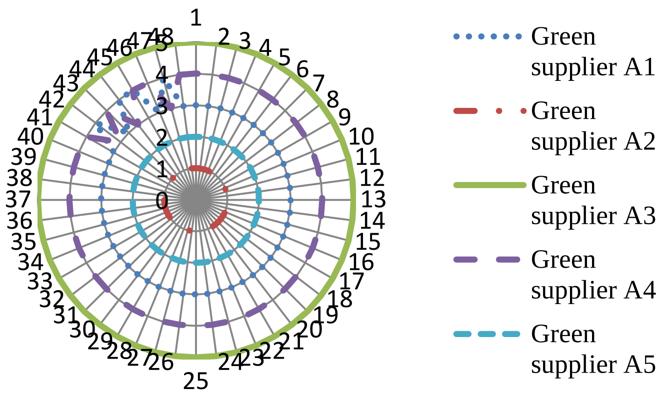

Figure 4. The sensitivity analysis result of green supplier sorting

From Fig 3 and Fig 4, $S(A_2)$ value and sorting value of green supplier A_2 are both the greatest and $S(A_3)$ value and sorting value of green supplier A_3 are both the smallest in the 48 experiments, in 3 of which the sorting of A_1 and A_4 has changed and the relative closeness is similar.

Therefore, the green supplier decision-making method in this paper is relatively insensitive to the change of the weight. The sorting of logistics suppliers only changed 3 times (6.25%) in 48 experiments. A_2 has no deviation as the optimal decision-making logistics supplier, so the decision-making result of the green supplier selection model is relatively effective and stable proposed in this paper. It is a correct decision to select green supplier A_2 as the logistics partner.

4. Conclusion

In this paper, we analyzed the problem of green supplier selection, and gave a concrete description of the green supplier in the intuitionistic fuzzy environment. In the problem of the third party logistics supplier selection with incomplete information, we considered that the weight information was completely unknown. We obtained the weight value of each evaluation index of the logistics supplier by using intuitionistic fuzzy set as theory tool, introducing the concept of entropy in information theory, proposing the intuitionistic fuzzy entropy weight method to determine the weight and with some simple but practical formulas. On this basis, we extended the traditional TOPSIS decision-making and established improved intuitionistic fuzzy TOPSIS green supplier selection model. This method is easy and can help enterprises quickly find out the suitable green logistics partners.

Although the research of this paper has made some achievements, but there are still some problems worthy of further research mainly including:

(1) Green supplier evaluation indexes selected in this paper adopt single evaluation value type, that is intuitionistic fuzzy set data type, but sometimes may also use language form

for evaluation values, or coexistence form mixed with subjective and objective data types. The types of evaluation decision need further study.

(2) In this paper, we studied the green supplier selection model which is based on complete information under uncertain conditions and the evaluation problem with missing information asks for further study and exploration.

Acknowledgements

This paper was supported by the National Natural Science Foundation of China (71271070) and Specialty of College Comprehensive Reform Pilot Project (ZG0429).

References

1. Wu J., Cao Q. W. (2012) A method for choosing green supplier under uncertain decision-making. *Operations research and management science*, 21(1), p.p.220-225.
2. Dickson G. W. (1966) An analysis of vendor selection systems and decisions. *Journal of Purchasing*, 2(1), p.p.5-17.
3. Weber C. A., Current J. R., Benton W. C. (1991) Vendor selection criteria and methods. *European Journal of Operational Research*, 50(1), p.p.2-18.
4. Beamon B. M. (1999) Designing the green supply chain. *Logistics Information Management*, 12(4), p.p.332-342.
5. 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(1), p.p.66-83.
6. Humphreys P., McCloskey A., McIvor R., Maguire L., Glackin C. (2006) Employing dynamic fuzzy membership functions to assess environmental performance in the supplier selection process. *International Journal of Production Research*, 44(12), p.p.2379-2419.
7. Shen L.; Olfat L., Govindan K., Khodaverdi R., Diabat A. (2013) A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences. *Resources, Conservation and Recycling*, 74(5), p.p.170-179.
8. Humphreys P., McIvor R., Chan F. (2003) Using case-based reasoning to evaluate supplier environmental management performance. *Expert Systems with Applications*, 25(2), p.p.141-153.
9. Humphreys P. K., Wong Y. K., Chan F. T. S. (2003) Integrating environmental criteria into the supplier selection process. *Journal of Materials Processing Technology*, 138(1-3), p.p.349-356.
10. Bai C., Sarkis J. (2010) Green supplier development: analytical evaluation using rough set theory. *Journal of Cleaner Production*, 18(12), p.p.1200-1210.
11. Kuo R. J., Lin Y. J. (2011) Supplier selection using analytic network process and data envelopment analysis. *International Journal of Production Research*, 50(10-12), p.p.2852-2863.
12. 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), p.p.1161-1170.
13. Atanassov K. (1986) Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 20(1), p.p.87-96.
14. Atanassov K. (1989) More on intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 33(1), p.p.37-45.
15. Atanassov K. (1994) New operations defined over the intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 61(2), p.p.137-142.
16. Zadeh L. A. (1965) Fuzzy sets. *Information Control*, 8(3), p.p.338-353.
17. Xu Z. S. (2007) Some similarity measures of intuitionistic fuzzy sets and their applications to multiple attribute decision making. *Fuzzy Optimization and Decision Making*, 6(2), p.p.109-121.
18. Hong D. H., Choi, C. H. (2000) Multicriteria fuzzy decision-making problems based on vague set theory. *Fuzzy Sets and Systems*, 114(1), p.p.103-113.
19. Wang J., Zhang J., Liu S. Y. (2006) A new score function for fuzzy MCDM based on vague set theory. *International Journal of Computational Cognition*, 4(1), p.p.44-48.
20. Liu H. W., Wang G. J. (2007) Multi-criteria decision-making methods based on intuitionistic fuzzy sets. *European Journal of Operational Research*, 179(1), p.p.220-233.
21. Li D. F., Chen C. T. (2002) New similarity measures of intuitionistic fuzzy sets and application to pattern recognitions. *Pattern Recognition Letters*, 23(1-3), p.p.221-225.
22. Wei C. P., Wang P., Zhang, Y. Z. (2011) Entropy, similarity measure of interval-valued intuitionistic fuzzy sets and their applications. *Information Sciences*, 181(19), p.p.4273-4286.
23. Simanaviciene R., Ustinovichius L. (2010) Sensitivity analysis for multiple criteria decision making methods: TOPSIS and SAW. *Procedia - Social and Behavioral Sciences*, 2(6), p.p.7743-7744.