Green Manufacturing Based on DE Algorithm in Probabilistic Language Environment Supply and Demand in the Supply Chain Matching Decision Methods

Xinlu Yao*, Jiangsha Ying
School of Mathematical Sciences, Huaqiao University, Quanzhou, China.
3020235524@qq.com

Abstract. With the strategy of "green manufacturing", it is especially important to develop from traditional manufacturing to low-carbon, low-cost, and environmentally friendly manufacturing with high quality and efficiency. Supply and demand matching in the supply chain is considered to be an effective way to improve the efficiency of manufacturing management. In dealing with the green supply chain supply and demand matching problem in a probabilistic language environment, this study proposes a decision-making method based on a differential evolution (DE) algorithm. By adopting a probabilistic language term set to express the supply and demand information structure of the supply chain, designs the corresponding utility function accordingly; Secondly, this paper establishes a bilateral matching model for the characteristics of the matching satisfaction, and solves the optimal matching solution through the evolutionary algorithm; Lastly, through the specific case, this study confirms that the method is effective.

Keywords: probabilistic linguistic term set; green supply chain; DE algorithm; supply-demand matching model.

1. Introduction

With the beginning of the new round of the industrial revolution, the development of the green industry presents the trend of combining intelligent and service-oriented. The global industrial system and competition mode are being reconstructed and taking the green and low-carbon development path has become an optional path for global economic development [1].At the same time, China is still deficient in the exploration of low-carbon and green supply chains and the future supply chain development mode will inevitably tend to be low-carbon and high-efficiency [2].

After Beamon proposed the concept of a green supply chain for the first time in 1999, domestic and foreign scholars conducted an in-depth study on green supply chains. The study by Beamon intended to summarize the domestic and foreign-related studies from three aspects: the structure of green supply chain, green supply chain management, and the evaluation of green supply chain [3]. Corresponding to the concept of green value chain, Carter and Rogers defined green supply chain management(SSCM) as the transparent integration and achievement of an organization's social, environmental, and economic goals to coordinate key inter-organizational business processes [4]. Donya et al [5] proposed a green supply chain model based on a two-channel system and proposed an optimization algorithm to obtain an efficient solution. Literature [6] designed a multi-objective approach to solve a green meat supply chain network.

In 1985, Roth, a professor at the University of Pittsburgh, first explicitly proposed the concept of "two-side matching", i.e., bilateral matching [7], and gave the specific meaning of "two-side matching", and then tried to solve the problems of kidney matching、medical student matching to internship hospitals [8] combining the game theory and other methods. With the development of society, the background of the matching problem becomes more and more complex. Currently, scholars are devoted to studying the bilateral matching problem under uncertain information. Li et al [9] proposed a bilateral matching method under probabilistic linguistic information and constructed a model to deal with the probabilistic linguistic evaluation information based on the definition of time satisfaction When dealing with the supply and demand data of the green manufacturing supply chain, the traditional model and algorithm for solving the bilateral matching problem do not fully take into account the uncertainty of the decision makers. Furthermore, the weight allocation of the indexes of supply and demand is often set manually.

In summary, the solution to the problem of matching supply and demand in green manufacturing supply chains is very important for realizing sustainable development and environmental protection. Although the existing research has provided theoretical and practical support for the development of a green manufacturing supply chain, it has not yet been well solved in practice how to effectively integrate the green manufacturing supply and demand matching in each link of the supply chain. Based on this, this study focuses on the application of accurate supply and demand matching in green manufacturing supply chains to carry out technological innovation research and expects to provide a reference for realizing the efficient management and sustainable development of green manufacturing supply chains by proposing new models, algorithms and implementation strategies.

2. Basics

2.1 Probabilistic language term set

In real life, decision-making problem solutions have a complex and variable nature, due to differences in decision-making environments, differences in experiences and preferences of decision-makers. When faced with a problem, decision-makers are usually unable to give a precise answer. They can only describe the evaluation information with a kind of vague linguistic terminology, such as "poor", "fair", "good", etc. A special set of linguistic terms describing decision-making information is called a linguistic term set.

Definition 1:$S=\{S_0,S_1,\dots,S_\tau\}$ is a set of linguistic terms, and the set of probabilistic linguistic terms can be defined as:

$$L(p)=\{L^{(k)}(p^{(k)})|L^{(k)}\in S,p^{(k)}\geq 0,k=1,2,\dots,\#L(p),\textstyle\sum_{k=1}^{\#L(p)}p^{(k)}\leq 1\} \tag{1}$$

Where$L^{(k)}(p^{(k)})$ denotes the linguistic term$L^{(k)}$and its associated probability$p^{(k)}$, and$\#L(p)$ denotes the number of different linguistic terms in the set of probabilistic linguistic terms$L(p)$. Since the positions of the elements in the set can be exchanged arbitrarily, the order$PLTS$is proposed to ensure that the result of the operation $PLTS$ can be determined directly.

Definition 2: Given a probabilistic linguistic term set$L(p)$, where$\sum_{k=1}^{\#L(p)}p^{(k)}<1$, the normalized probabilistic linguistic term set is defined as:

$$\overline{L}(p)=\{L^{(k)}(\overline{p}^{(k)})|L^{(k)}\in S,\overline{p}^{(k)}\geq 0,k=1,2,\dots,\#L(\overline{p}),\textstyle\sum_{k=1}^{\#L(\overline{p})}\overline{p}^{(k)}=1\} \tag{2}$$

which is$\overline{p}^{(k)}=p^{(k)}/\sum_{k=1}^{\#L(p)}p^{(k)},k=1,2,\dots,\#L(p)$.

Definition 3:$L(p)=\{L^{(k)}(p^{(k)})|k=1,2,\dots,\#L_1(p)\}$ is a$PLTS$ and$\gamma^{(k)}$is the subscript of the$k$ linguistic term$L^{(k)}$ and$E(L(p))=s_{\overline{\alpha}}$, $\overline{\alpha}=\sum_{k=1}^{\#L(p)}\gamma^{(k)}p^{(k)}/\sum_{k=1}^{\#L(p)}p^{(k)}$.

The deviation degree is:

$$\sigma(L(p))=\frac{(\sum_{k=1}^{\#L(p)}(p^{(k)}(\gamma^{(k)}-\overline{\alpha}))^2)^{1/2}}{\sum_{k=1}^{\#L(p)}p^{(k)}} \tag{3}$$

2.2 Bilateral matching

The bilateral matching model refers to the process in which the matching decision maker calculates the matching degree of the two subjects according to the evaluation preference information and relevant attribute information of the two sides, to achieve the process of forming the optimal matching pairs of the two subjects. Let$A=\{A_1,A_2,\cdots,A_m\},m\geq 2$denote the set of subjects of side, whereA_i represents the$i$ th$A$ subject$(i=1,2,\cdots,m)$; Similarly, the set of subjects of side$B$ can be denoted as $B=\{B_1,B_2,\cdots,B_n\},n\geq 2$, where B_j represents the j th B subject $(j=1,2,\cdots,n)$。 Remember$I=\{1,2,\cdots,m\},J=\{1,2,\cdots,n\}$。 [10]

Definition 4:A bilateral match can be defined as a mapping (E)$\mu\colon A\cup B\to A\cup B$, $\forall A_i\in A,\forall B_j\in B,\mu$ subject to the following conditions:

(1)$\mu(A_i) \in B \cup \{A_i\}, \mu(A_i) = A_i$, It means that$A_i$did not match the object successfully;

(2)$\mu(B_j) \in A \cup \{B_j\}, \mu(B_j) = B_j$, It means that$B_j$did not match the object successfully;

(3)$\mu(A_i) = B_j$, We call(A_i, B_j) a matching pair identified under the mapping of the bilateral matching model if and only if$\mu(B_j) = A_i$, and at the same time we call the set of all matching pairs the set of matching schemes, denoted as$F$.

3. Optimization and Solution of Multi-Attribute Bilateral Matching Model Based on Probabilistic Linguistic Information

3.1 Description of the problem

This study focuses on the supply chain decision-making problem in the field of green manufacturing and uses a bilateral matching model under probabilistic linguistic information. $C^1 = \{C_1^1, C_2^1, \cdots, C_s^1\}$ is the set of criteria for the evaluation of the subject $A_i(i \in I)$ of$A$against the subject$B_j(j \in J)$ of$B$, and$C_q^1(q \in Q = \{1, 2, \cdots, s\})$denotes the$q$ criterion for the evaluation of the subject$A$ against the subject$B$. $C^2 = \{C_1^2, C_2^2, \cdots, C_s^2\}$is the set of criteria for the evaluation of the subject $B_j(j \in J)$ of B against the subject $A_i(i \in I)$ of A, and $C_\rho^1(\rho \in H = \{1, 2, \cdots, h\})$ denotes theρcriterion for the evaluation of the subject$A$ against the subject$B$ [11].

For the evaluation criteriaC_p^1, the probabilistic uncertainty of the linguistic information given by the subject$A_i$of the$A$side to the subject$B_j$of the$B$side:

$$\varepsilon_{qij}(p) = \{\left\langle [s_{L_{qij}^k}, s_{U_{qij}^k}], P_{qij}^k \right\rangle | k = 1, 2, \cdots, \#\varepsilon_{qij}(P)\}$$
$$(s_{L_{qij}^k} \leq s_{U_{qij}^k}, 0 < \sum_{k=1}^{\#\varepsilon_{qij}(P)} P_{qij}^k \leq 1, i \in I, j \in J, q \in Q) \quad (4)$$

For the evaluation criterionC_q^2, the probabilistic uncertainty of the linguistic information given by the subject $B_j$of the$B$ side to the subjectA_i of the$A$ side:

$$\tilde{\varepsilon}_{\rho ij}(p) = \{\left\langle [\tilde{s}_{L_{\rho ij}^k}, \tilde{s}_{U_{\rho ij}^k}], \tilde{P}_{\rho ij}^k \right\rangle | k = 1, 2, \cdots, \#\tilde{\varepsilon}_{\rho ij}(P)\}$$
$$(\tilde{s}_{L_{\rho ij}^k} \leq \tilde{s}_{U_{\rho ij}^k}, 0 < \sum_{k=1}^{\#\varepsilon_{\rho ij}(P)} \tilde{P}_{\rho ij}^k \leq 1, i \in I, j \in J, \rho \in H) \quad (5)$$

We aim to construct a matching optimization model and get the best matching pair result. The model needs to ensure the satisfaction and fairness of both subjects in bilateral matching based on effectively utilizing the probabilistic linguistic information$\varepsilon_{qij}(P)\}$ $\#\tilde{\varepsilon}_{\rho ij}(P)$ of one subject to the other subject under different evaluation criteria.

3.2 The process of model building

3.2.1 Calculating Matching Satisfaction Based on Regret Theory

Based on the supply-demand matching decision of green supply chains, this paper pays special attention to the avoidance psychology of decision-makers when they face potential regrets in the matching process of green supply chains. To cope with this phenomenon, this paper integrated the probabilistic linguistic term set theory and the regret theory and proposes a model that combines these two theories to deal with probabilistic linguistic term sets.

Given a set of probabilistic linguistic terms$L(p) = \{L^{(k)}(p^k) | k = 1, 2, \cdots, \#L(p)\}$, we first compute the value of its score function$S_{\bar{\alpha}}$and then define the utility function$v(\bullet)L(p)$ as follows:

$$v(L(p)) = v(\bar{\alpha}) = (\frac{\bar{\alpha}+1}{\tau+1})^\theta (\theta > 0) \quad (6)$$

Where$\bar{\alpha} = \frac{\sum_{k=1}^{\#L(p)} r^{(k)} p^k}{\sum_{k=1}^{\#L(p)} p^k}$, $0 \leq \overline{\alpha} \leq \tau$. Due to this$0 \leq \theta \leq 1$, we can easily get $v(\bar{\alpha})$ a concave function. Lastly, we can get$0 \leq (\frac{\bar{\alpha}+1}{\tau+1})^{\theta} \leq 1$. At the same time, we can know that $v(D_i^j) = (v(d_{ij}^o))_{m \times O}$ according to the utility function matrix, In the evaluation of B_j the subject A_i, let the lowest acceptable degree of evaluation index E_o' be m_{ij}^o, and also note that M^j is the lowest satisfaction decision matrix under each index. Next, we can calculate the utility value of the lowest acceptable degree $v(m_{ij}^o)$. Besides, we utilize a new regret elation function as follows:

$$R(d_{ij}^o) = \begin{cases} -Z, & if \quad v(d_{ij}^o) < v(m_{ij}^o) \\ 1 - exp(-\delta(v(d_{ij}^o) - v_o^{j^*})), & if \quad v(d_{ij}^o) \geq v(m_{ij}^o) \end{cases} \quad (7)$$

where $v_o^{j^*} = max\{v(d_{ij}^o)\}$, Z is a sufficiently large positive number.

The perceived utility d_{ij}^o is calculated as follows:

$$u(d_{ij}^o) = v(d_{ij}^o) + R(d_{ij}^o) \quad (8)$$

According to the attribute weights $W_o^{E'}$, the overall perceived utility can be calculated as follows:

$$u^j(A_i) = \sum_{o=1}^{O} w_o^{E'} u(d_{ij}^o) \quad (9)$$

Similarly, for the decision matrix $D_j^i = (d_{ij}^p)_{n\times p}$, we can obtain the utility function matrix $v(D_i^j) = (v(d_{ij}^p))_{n\times P}$.

Let the minimum acceptable level of the evaluation indicator F_p' in the assessment of A_i the matching subject B_j be m_{ij}^p, and note that the decision matrix of the lowest acceptable degree under each index is M^i. Then, we can determine the utility values $v(m_{ij}^p)$、regret values d_{ij}^p , and the perceived utility d_{ij}^p. Setting the attribute weights to $W_p^{F'}$, the overall perceived utility of B_j over A_i can be calculated too.

For the sake of the later discussion, the overall perceived utility as match satisfaction is denoted as $U_{ij} = u^j(A_i)$ and $\overline{U}_{ij} = u^i(B_j)$.

3.2.2 Supply and demand matching model and solution based on DE algorithm

To optimize the bilateral matching process in a green supply chain, this study proposes a multi-objective optimization framework focusing on satisfaction maximization. The framework focuses on the interactions between suppliers and manufacturers to ensure that both sides reach the optimal level of satisfaction while introducing a minimum satisfaction threshold as a constraint to ensure the quality and feasibility of the matching results:

$$maxZ_1 = \sum_{i=1}^{m}\sum_{j=1}^{n} U_{ij}x_{ij} \quad (a)$$

$$maxZ_2 = \sum_{i=1}^{m}\sum_{j=1}^{n} \overline{U}_{ij}x_{ij} \quad (b)$$

$$(P1) \quad s.t \sum_{j=1}^{n} x_{ij} \leq 1, i = 1,2,\cdots,m \quad (c)$$

$$\sum_{i=1}^{m} x_{ij} \leq 1, j = 1,2,\cdots,n \quad (d)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}(U_{ij} + \overline{U}_{ij})x_{ij} \geq 2(2 - e^{2\delta})mn \quad (e)$$

$$x_{ij} = 0 \quad or \quad 1, i = 1,2,\cdots,n \quad (f)$$

In the above bilateral matching model, the objective functions (a) to (b) define the core purpose of the model, i.e., to achieve the goal of maximizing the satisfaction of both subjects in the context of a green manufacturing supply chain. Eqs. (c)-(d) denotes that the subjects of this bilateral matching model practice one-to-one matching. Eq. (e) denotes the constraints for the minimum acceptability threshold, and Eq. (5.8f) denotes the quantitative constraints. If $x_{ij} = 0$, it means that no match is reached between these two subjects and vice versa $x_{ij} = 1$. For constraint (e):

$\sum_{i=1}^{m}\sum_{j=1}^{n}(U_{ij} + \overline{U}_{ij})x_{ij} \geq 2(2 - e^{2\delta})mn$ because of $U_{ij} \leq 1 + {}_{1\text{-}}e^{2\delta}$ and $\overline{U}_{ij} \leq 1 + {}_{1\text{-}}e^{2\delta}$. In solving the model, this paper utilizes a linear weighting approach. The weights of the objective functions Z_1 and Z_2 are w_1 and w_2 , $0 \leq w_1, w_2 \leq 1$ and $w_1 + w_2 = 1$ respectively.

Then the single objective function can be expressed as:

$$max\, Z = w_1Z_1 + w_2Z_2 \quad (a)$$

$$(P2) \quad s.t \sum_{j=1}^{n} x_{ij} \leq n, i = 1,2,\cdots,m \quad (b)$$

$$\sum_{i=1}^{m} x_{ij} \leq 1, j = 1,2,\cdots,n \quad (c)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}(U_{ij}+\overline{U}_{ij})x_{ij}\geq 2(2-e^{2\delta})mn \quad \text{(d)}$$

$$x_{ij}=0 \quad or \quad 1, i=1,2,\cdots,n \quad \text{(e)}$$

Due to the principle of bilateral equality, we assign the same weight to both objective functions, i.e.w_1 $w_2$are equal. However, in special cases, where special attention needs to be paid to the satisfaction of side B, the values of$w_1$and$w_2$may not be equal.

The bilateral matching model developed in this paper is a multi-objective 0-1 linear programming problem, which is a typical NP problem. As the number of objectives increases, the difficulty of finding a solution rises. Given that the differential evolution (DE) algorithm exhibits high efficiency and speed in solving multi-objective optimization problems, this study chooses to adopt the DE algorithm as a solution tool.

As a result of the above analysis, we summarize the main decision-making steps, as shown in Figure 3.

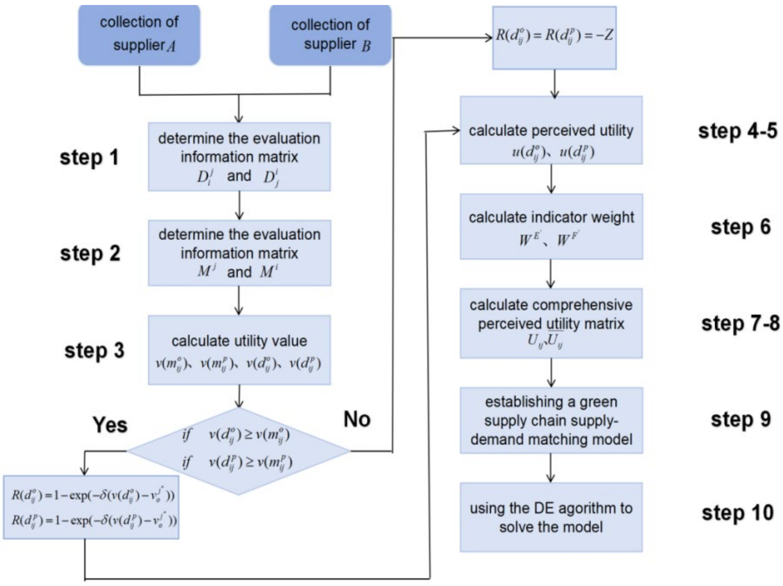

Fig. 1 Main decision-making steps of matching decision-making method of supply and demand in green manufacturing supply chain based on regret theory

4. Matching model application cases

4.1 Matching Pattern Construction

Step 1: Collect rating information

This paper is based on providing the corresponding supply and demand matching counseling between the supply side and the demand side. Let the set of three suppliers be denoted as$A=(A_1,A_2,A_3)$ and the set of subjects on the demand side be denoted as $B=(B_1,B_2,B_3)$. The two sides are matched on a one-to-one basis. The evaluation criteria of the supply side to the demand side represent environment, economy, quality and timeliness, and future development respectively. The evaluation indexes of the demand side to the supply side are$F_p{}''=\{F_1'',F_2'',F_3'',F_4''\}$, which represent the demand side's participation, late publicity, sense of ethics, and green and low-carbon concepts, respectively.

About environment, it includes supplier's level of environmental certification, degree of waste reduction. About economy, it includes the supplier's cost of complying with environmental laws, resource utilization. About quality and timeliness, it includes the purchasing cycle, on-time delivery rate, new product development cycle[12].About development, it includes the proportion of suppliers' R&D personnel and the education level of their employees.

About participation, it includes the degree of cooperation of the demand side in returning end-of-life products, the degree of dissemination of recycling information, [13]. About post-publicity, it includes the strength of publicity of favorable products and the degree of cooperation in experience surveys. About the sense of morality, it includes the degree of truthfulness of the product evaluation of the demand side. About the green and low-carbon concept, it includes the frequency of purchase of the demand side's green and low-carbon products. In terms of green and low-carbon concepts, it includes the frequency of purchasing green and low-carbon products.

We determine the mutual evaluation matrix between the matching sides of the demand side and the supply side of the green manufacturing supply chain.

$$D_i^j = (d_{ij}^o)_{m\times O} 、 D_j^i = (d_{ij}^p)_{n\times P} \quad (10)$$

Table 1 Information on supply-side evaluation of the demand side

	$E_1^{''}$	$E_2^{''}$	$E_3^{''}$	$E_4^{''}$
A_1-B_1	{S1(0.1), S4(0.5). S6(0.4)}	{S1 (0.2), S4 (0.7), S5 (0.1)}	{S2(0.4), S3(0.3), S6(0.3)}	{S2(0.3), S6(0.7)}
A_1-B_2	{S3(0.5), S4(0.5)}	{S1(0.1), S4(0.5). S6(0.4)}	{S6(0.3), S7(0.7)}	{S2(0.3), S5(0.7)}
A_1-B_3	{S3(0.3), S4(0.7)}	{S1(0.2), S5(0.8)}	{S2(0.5), S5(0.4), S6(0.1)}	{S5(0.7), S6(0.3)}
A_2-B_1	{S3(0.5), S4(0.5)}	{S5(0.3), S6(0.7)}	{S1(0.2), S6(0.8)}	{S0(0.2), S6(0.8)}
A_2-B_2	{S2(0.1), S4 (0.7), S6 (0.2)}	{S1(0.4), S3(0.5), S4(0.1)}	{S2(0.6), S6(0.4)}	{S1(0.3), S6(0.7)}
A_2-B_3	{S4(0.6), S6(0.4)}	{S3(0.4), S4(0.2), S5(0.4)}	{S2(0.5), S4(0.3), S6(0.2)}	{S4(0.2), S5(0.5), S6(0.3)}
A_3-B_1	{S0(0.5), S6(0.5)}	{S4(0.5), S6(0.5)}	{S1(0.3), S4(0.7)}	{S2(0.2), S6(0.8)}
A_3-B_2	{S2(0.5), S3(0.3), S6(0.2)}	{S5(0.7), S6(0.3)}	{S2(0.4), S3(0.3), S6(0.3)}	{S3(0.5), S5(0.5)}
A_3-B_3	{S1(0.1), S3(0.7), S6(0.2)}	{S0(0.5), S6(0.5)}	{S5(0.5), S4(0.5)}	{S0(0.2), S3(0.7), S4(0.1)}

Table 2 Demand-side information on supply-side evaluation

	$F_1^{''}$	$F_2^{''}$	$F_3^{''}$	$F_4^{''}$
B_1-A_1	{S4(0.4), S5(0.5), S6(0.1)}	{S1 (0.2), S4 (0.5), S5 (0.1), S6 (0.2)}	{S1(0.1), S2(0.5), S6(0.4)}	{S2(0.5), S4(0.3), S5(0.1), S6(0.1)}
B_1-A_2	{S3(0.5), S4(0.2), S5(0.3)}	{S2(0.5), S6(0.5)}	{S3(0.3), S4(0.7)}	{S2(0.3), S5(0.5), S6(0.2)}
B_1-A_3	{S3(0.3), S4(0.7)}	{S1(0.1), S3(0.9)}	{S2(0.2), S3(0.4), S6(0.4)}	{S0(0.2), S4(0.3), s5(0.4), s6(0.1)}
B_2-A_1	{S1(0.1), S5(0.2), S6(0.7)}	{S1(0.3), S5(0.7)}	{S1(0.2), S4(0.7), S5(0.1)}	{S0(0.2), S6(0.8)}
B_2-A_2	{S2(0.2), S4(0.3), S5(0.4), s6(0.1)}	{S1(0.2), S3(0.5), S4(0.3)}	{S5(0.6), S6(0.4)}	{S1(0.1), S5(0.2), S6(0.7)}
B_2-A_3	{S4(0.8), S6(0.2)}	{S3(0.4), S4(0.2), S5(0.2), s6(0.2)}	{S2(0.5), S4(0.1), S6(0.4)}	{S0(0.3), S6(0.7)}
B_3-A_1	{S1(0.1), S4(0.3), S6(0.7)}	{S1(0.5), S2(0.2), S4(0.1), s6(0.2)}	{S3(0.5), S5(0.5)}	{S2(0.5), S4(0.1), S6(0.4)}
B_3-A_2	{S2(0.1), S3(0.3), s4(0.2), s5(0.4)}	{S1(0.1), S4(0.3), S6(0.7)}	{S2(0.7), S4(0.3)}	{S4(0.4), S5(0.5), S6(0.1)}

$B_3 - A_3$	{S0(0.1), S3(0.6), S6(0.3)}	{S4(0.5), S6(0.5)}	{S2(0.5), S3(0.2), S5(0.1), S6(0.2)}	{S1(0.1), S4(0.3), S6(0.7)}

Step 2: Determine the minimum acceptable decision matrix for the demand side and the supply sideM^j 、 M^i. The minimum expectations that the supply side can accept from the demand side and the minimum expectations that the demand side can accept from the supply side are both set to be$\{S_2\}$.

Step 3: The perceived utility ofd_{ij}^o is obtained as $u(d_{ij}^o)$.

Table 3 d_{ij}^o Perceived utility values

M^j	A_1				A_2				A_3			
	E_1''	E_2''	E_3''	E_4''	E_1''	E_2''	E_3''	E_4''	E_1''	E_2''	E_3''	E_4''
B_1	0.72	0.55	0.55	0.77	0.55	0.72	1.09	0.65	0.58	0.67	0.56	0.86
B_2	0.55	0.92	0.81	0.77	0.67	0.33	0.56	0.72	0.77	0.63	0.53	0.82
B_3	0.46	0.81	0.47	0.84	0.47	0.86	0.55	0.63	0.53	0.46	0.89	0.37

Step 4: The perceived utility ofd_{ij}^p is obtained as$u(d_{ij}^p)$.

Table 4 Perceived utility values ford_{ij}^p

M^j	A_1				A_2				A_3			
	E_1''	E_2''	E_3''	E_4''	E_1''	E_2''	E_3''	E_4''	E_1''	E_2''	E_3''	E_4''
B_1	0.80	0.67	0.60	0.56	0.65	0.68	0.63	0.73	0.63	0.47	0.68	0.65
B_2	0.90	0.65	0.60	0.82	0.72	0.49	0.92	0.90	0.75	0.72	0.65	0.72
B_3	0.94	0.63	0.68	0.65	0.67	0.94	0.44	0.80	0.61	0.85	0.56	0.94

Step 5: Determine indicator weights$W^{E'}$ 、 $W^{F'}$

$$({W^{E'}}_1, {W^{E'}}_2, {W^{E'}}_3, {W^{E'}}_4) = (0.25, 0.30, 0.24, 0.21)$$
$$({W^{F'}}_1, {W^{F'}}_2, {W^{F'}}_3, {W^{F'}}_4) = (0.10, 0.20, 0.35, 0.35)$$

Step 6: The overall perceived utility value of the matching subjectA_i $B_j$is calculated as$u^j(A_i)$.

$$U_{ij} = \begin{bmatrix} 0.64 & 0.35 & 0.51 \\ 0.77 & 0.27 & 0.25 \\ 0.65 & 0.38 & 0.38 \end{bmatrix}$$

Step 7: The overall perceived utility value of the matching subjectB_j A_i is calculated as$u^i(B_j)$.

$$\overline{U_{ij}} = \begin{bmatrix} 0.62 & 0.68 & 0.62 \\ 0.72 & 0.81 & 0.70 \\ 0.69 & 0.69 & 0.76 \end{bmatrix}$$

4.2 Matching model solving

We build the objective function of the model:

$$max \quad Z_1 = 0.64 * x_{11} + 0.35x_{12} + 0.51x_{13} + 077x_{21} + 0.27x_{22} + 0.25x_{23} + 0.65x_{31} + 0.38x_{32} + 0.38x_{33}$$
$$max \quad Z_2 = 0.62x_{11} + 0.68x_{12} + 0.62x_{13} + 0.72x_{21} + 0.81x_{22} + 0.70x_{23} + 0.69x_{31} + 0.69x_{32} + 0.76x_{33}$$
$$max \quad Z = w_1Z_1 + w_2Z_2$$
$$x_{11} + x_{12} + x_{13} \leq 1$$
$$x_{21} + x_{22} + x_{23} \leq 1$$
$$x_{31} + x_{32} + x_{33} \leq 1$$
$$x_{11} + x_{21} + x_{31} \leq 1$$
$$x_{12} + x_{22} + x_{32} \leq 1$$
$$x_{13} + x_{23} + x_{33} \leq 1$$
$$1.26x_{11} + 1.03x_{12} + 1.13x_{13} + 1.48x_{21} + 1.07x_{22} + 0.95x_{23} + 1.33x_{31} + 1.06x_{32} + 1.13x_{33} \geq 2 * (2 - exp(0.6)) * 9$$

$x_{ij} = 0\ or\ 1\ (i = 1,2,3;\ j = 1,2,3)$

Six solutions were found by the DE algorithm:

Table 5 Solution set

	x_{11}	x_{12}	x_{13}	x_{21}	x_{22}	x_{23}	x_{31}	x_{32}	x_{33}
Solution 1	1	0	0	0	1	0	0	0	1
Solution 2	1	0	0	0	0	1	0	1	0
Solution 3	0	1	0	1	0	0	0	0	1
Solution 4	0	1	0	0	0	1	1	0	0
Solution 5	0	0	1	0	1	0	1	0	0
Solution 6	0	0	1	1	0	0	0	1	0

Table 6 Final pairing of programs

serial number	pairing result	Z_1	Z_2	Total satisfaction
1	$\{A_1,B_1\}$, $\{A_2,B_2\}$, $\{A_3,B_3\}$	1.29	2.12	3.41
2	$\{A_1,B_1\}$, $\{A_2,B_3\}$, $\{A_3\ ,\ B_2\ \}$	1.27	2.01	3.28
3	$\{A_1,B_2\}$, $\{A_2,B_1\}$, $\{A_3,B_3\}$	1.5	2.16	3.66
4	$\{A_1,B_2\}$, $\{A_2,B_3\}$, $\{A_3,B_1\}$	1.25	2.07	3.32
5	$\{A_1,B_3\}$, $\{A_2,B_2\}$, $\{A_3\ ,\ B_1\}$	1.43	2.12	3.55
6	$\{A_1,B_3\}$, $\{A_2,B_1\}$, $\{A_3,B_2\}$	1.66	2.03	3.69

4.3 Discussion of Matching Stability

Through the above calculations, we finally obtained six final pairing results by NSGA-II algorithm. According to the total satisfaction, $\{A_1,B_3\}$, $\{A_2,B_1\}$, $\{A_3,B_2\}$is the pairing with the highest satisfaction. However, the stability of the matching is also an important factor to be taken into account in the bilateral matching problem. The stability of the matching reflects the overall acceptance of the matching relationship generated by the bilateral matching mechanism by the individuals on both sides of the matching. The stability of matching reflects the overall acceptance of the matching relationship generated from the bilateral matching mechanism by the individuals of the two matching sides. If there are unstable matching pairs in the matching relationship, there are individuals who do not accept the matching relationship generated by bilateral matching. The more unstable matching pairs exist in the matching relationship, the lower the overall acceptance of the matching relationship.

From the pairing schemes, we can see that we need to prioritize the pairing of $\{A_2,B_1\}$ by analyzing the case of Z_1. To maximize the value of Z_1, the priority of the pairing Z_1 is $\{A_2,B_1\}>\{A_1,B_3\}>\{A_1,B_2\}$. Analyzing the case of Z_2, we need to prioritize the pairing of $\{A_3,B_3\}$ to maximize the value of Z_2, The pairing priority of Z_2 is $\{A_3,B_3\ \}>\{A_1,B_3\ \}>\ \{A_2,B_2\ \}$. In Scheme 3, $\{A_1,B_2\}$, $\{A_2,B_1\}$, $\{A_3,B_3\}$ have advantages in each numerical analysis. However, the overall satisfaction is not the highest, with a value of 3.66, which is not much different from the value of 3.69 in Scheme 6. Therefore, it can be seen that scheme 3 $\{A_1,B_2\}$, $\{A_2,B_1\}$, $\{A_3,B_3\}$ is the best pairing scheme.

5. Research Conclusion and Outlook

Addressing the existing green manufacturing supply chain supply and demand matching problem, this paper researches the matching modeling technique, comprehensively considers the linguistic evaluation information, adopts the probabilistic linguistic term set to represent the supply and demand information structure of the supply chain, designs the utility function by using the avoidance psychology of regret, establishes a bilateral matching model based on the regret theory, solves the problem by using the DE algorithm, and successfully verifies the method in handling the feasibility of this method in dealing with supply and demand matching problem in the green supply chain by case analysis. With the help of circular language terminology theory and bilateral matching theory, it provides an innovative perspective for the matching strategy of creating a green manufacturing supply chain, which is aimed at helping enterprises enhance their green management capability and provides a worthy methodology for green supply chain and its related research fields.

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