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A Hybrid MCDM Approach for Large Group Green Supplier Selection with Uncertain Linguistic Information

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ABSTRACT With increasing global concerns toward environmental protection and sustainable development, green supply chain management (GSCM) has drawn much attention from academicians and practitioners. Selecting an optimal green supplier is a critical part of GSCM, which can be viewed as a kind of multi-criteria decision making (MCDM) problem. To derive the best result, large group of decision makers are often involved in the green supplier selection nowadays. Besides, decision makers tend to express their evaluations utilizing uncertain linguistic terms due to the vagueness of human thinking. Hence, this paper aims to propose a hybrid MCDM approach for green supplier selection within the large group setting. More concretely, interval-valued intuitionistic uncertain linguistic sets (IVIULSs) are applied for assessing the performance of green suppliers concerning each criterion. Ant colony algorithm is utilized to cluster decision makers into several subgroups. The linear programming technique for multidimensional analysis of preference (LINMAP) is adopted for the determination of the optimal weights of criteria objectively. Finally, an extended MULTIMOORA approach is utilized to generate the ranking of alternative suppliers. The practicality and usefulness of the developed large group green supplier selection framework is illustrated using an empirical example of a real estate company.

INDEX TERMS Supply chain management, Green supplier selection, Ant colony algorithm, Interval-valued intuitionistic uncertain linguistic set, MULTIMOORA method, LINMAP approach.

I. INTRODUCTION

Because of growing public concerns over the environmental issues and government regulations toward sustainable development, green supply chain management (GSCM) has become popular in production operation management of modern enterprises [1]. By integrating environmental concerns into supply chain practices, GSCM is considered as a promising approach to improve the commercial benefit and environmental performance of organizations simultaneously. The major aim of GSCM is to decrease environmental pollution and eliminate waste during the process of purchasing, manufacturing, distributing and selling products [2]. As a result, there are a lot of programs for companies to implement GSCM, including green design, green production, green transportation and green marketing [3]. But an organization's environmental performance depends on not only its own green efforts but also its providers' green practices. Thus, selecting the optimal green supplier is a vital part of the GSCM for firms to develop sustainability [4-6].

Green supplier selection determines the best supplier which is capable of providing the buyer with high quality, low cost, quick return and good environmental performance simultaneously [7]. It plays a vital role in maintaining the competitive advantages of a company [8]. An appropriate green supplier makes a great difference in enhancing quality of end products and satisfaction degree of customers. The application of green supplier selection can be presented in the situation of multiple suppliers throughout a product's life-cycle [9]. Consequently, it is significant for organizations to choose the environmentally, socially and economically powerful suppliers. Moreover, a large group of decision makers from different backgrounds should be

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involved in the green supplier selection process due to the increasing complexity of the problem.

In previous studies, many scholars have applied fuzzy set theory [10] and intuitionistic fuzzy sets (IFSs) [11] to cope with the vague evaluations of decision makers and improve the effectiveness of green supplier selection. However, when transforming linguistic assessments of alternatives into fuzzy numbers, the information of decision makers' subjective judgements may be lost and distorted [12]. As for IFSs, the membership and non-membership degrees are signified by exact values, which cannot well handle the uncertainty and fuzziness of assessment information. Recently, Liu [13] proposed the concept of interval-valued intuitionistic uncertain linguistic sets (IVIULSs), which are the combination of uncertain linguistic variables and interval-valued intuitionistic fuzzy sets (IVIFSs). The linguistic variable, membership degree and nonmembership degree of each element in an IVIULS are denoted by interval values rather than crisp values, which can better capture the ambiguity and uncertainty of evaluation information. Owing to its characteristics and merits, the IVIULS theory has been utilized in different fields [14-16]. Therefore, it is natural to use the IVIULSs to evaluate the green performance of alternative suppliers on each criterion.

On the other hand, selecting the best-fit green supplier is often viewed as a multi-criteria decision making (MCDM) problem and a variety of MCDM approaches have been used for green supplier selection in recent years [1, 3, 4, 6]. The multi-objective optimization by a ratio analysis plus full multiplicative form (MULTIMOORA) method is a distinctive MCDM technique proposed by Brauers and Zavadskas [17]. It includes three parts as follows: the ratio system, the reference point and the full mutiplicative form [18]. The final ranking of alternatives is made in accordance with the dominance theory [19]. Comparing with other MCDM methods, the merits of the MULTIMOORA approach are that: (1) It can make the ranking result more accurate by aggregating the three basic parts; (2) It can effectively solve complicated MCDM problems with numerous alternatives and criteria; (3) Its calculation process is easily comprehensible and the result can be obtained rapidly. Hence, it is desirable to apply the MULTIMOORA method to address green supplier selection problems.

Against the above discussions, we propose a hybrid MCDM model based on IVIULSs and MULTIMOORA method in this paper for evaluating and ranking green suppliers under large group environment. We utilize ant colony algorithm to cluster decision makers, an extended LINMAP approach to calculate the objective weights of criteria, and an improved MULTIMOORA technique to rank alternative green suppliers. The presented large group green supplier selection approach is able to reflect the vagueness and ambiguity of decision makers' judgements and acquire an accurate ranking result of green suppliers. The remaining sections of this paper are arranged as follows: In Section II, we review the existing green supplier selection approaches and the applications of the MULTIMOORA technique. The basic concepts and definitions regarding to IVIULSs are introduced in Section III. In Section IV, we put forward a hybrid MCDM model using IVIULSs and MULTIMOORA method for large group green supplier selection. In Section V, a case of a real estate company in China is given to demonstrate the proposed approach. The last section presents concluding remarks and future research recommendations.

II. LITERATURE REVIEW

A. GREEN SUPPLIER SELECTION METHODS

In recent decade, a lot of green supplier selection methods based on MCDM have been developed, which can be classified into individual methods and hybrid methods [20]. As for individual methods, Sanayei et al. [21] utilized fuzzy VIKOR (VIsekriterijumska optimizacija i KOmpromisno Resenje) method to solve the supplier selection problem. Chen and Zou [22] applied intuitionistic fuzzy grey relational analysis (GRA) to find the best-fit supplier from the perspective of risk aversion. Çebi and Otay [23] used the best worst method (BWM) to choose the optimum green supplier for an edible oil company. You et al. [24] used a modified VIKOR method for green supplier selection with interval 2-tuple linguistic information. Keshavarz Ghorabaee et al. [25] proposed an improved complex proportional assessment (COPRAS) technique to select the optimum supplier in the interval type-2 fuzzy context.

In addition, many hybrid MCDM models have been utilized to deal with green supplier selection problems. For instance, Gary Graham et al. [26] offered a new model by integrating analytic hierarchy process (AHP) and TOPSIS for selecting the optimal green supplier. Wang et al. [27] proposed a hybrid MCDM model based on cloud model and QUALIFLEX method to evaluate the green performance of suppliers. In [28], intuitionistic fuzzy AHP and intuitionistic fuzzy axiomatic design were integrated to handle the green supplier selection problem for an international sporting goods firm. Tsui [29] developed an innovative MCDM model by combining DEMATEL-based analytic network process (DANP) and PROMETHEE to select the best green supplier in the thin film transistor liquid crystal display industry. Qin et al. [1] presented the TODIM technique based on prospect theory for the selection of green suppliers under interval type-2 fuzzy setting. Yazdani [30] designed a green supplier selection model, where DEMATEL method was utilized to handle the inter-relationships between customer requirements, quality function development (QFD) technique was used for constructing the relationship matrix between supplier selection criteria and customer requirements, and COPRAS method was adopted to prioritize the candidate suppliers. Furthermore, a more specific literature review relating to the methods of green supplier estimation and selection can be seen in [31, 32].

B. APPLICATIONS OF MULTIMOORA METHOD

In recent years, researchers have made considerable extensions of the MULTIMOORA method to handle various MCDM problems. For example, Zavadskas et al. [33] put forward a modified MULTIMOORA method based on IVIFSs to address civil engineering problems. Liu et al. [34] extended the MULTIMOORA method under the interval 2-tuple linguistic context for evaluating and selecting health-care waste treatment technologies. Deliktas and Ustun [35] proposed a hybrid method by integrating fuzzy MULTIMOORA method and multichoice conic goal programming to elect the best student. Hafezalkotob and Hafezalkotob [36] developed a MCDM model on the basis of MULTIMOORA method and Shannon entropy for managing material selection problem. Li [37] developed an extension MULTIMOORA method in the context of hesitant fuzzy numbers for software selection. Liu et al. [38] applied the MULTIMOORA method and fuzzy sets for the prevention of infant abduction. Tian et al. [39] developed an improved MULTIMOORA method by integrating simplified neutrosophic linguistic normalized weighted Bonferroni mean, simplified neutrosophic linguistic normalized geometric weighted Bonferroni mean operators and a simplified neutrosophic linguistic distance measure. Sahu et al. [40] presented an improved MULTIMOORA method in interval-valued trapezoidal fuzzy context to evaluate and rank computer numerical control machine tools. Hafezalkotob and Hafezalkotob [41] proposed a target-based MULTIMOORA method combined with significant coefficients for biomaterials selection. Lazauskas et al. [42] used AHP, additive ratio assessment (ARAS) and MULTIMOORA to assess unfinished residential buildings and choose the most appropriate construction project. Stanujkic et al. [43] described an extended MULTIMOORA by interval-valued triangular fuzzy numbers for selecting comminution circuits design scheme. Aytaç et al. [44] offered a MCDM model based on the MULTIMOORA and multi-objective optimization simple ratio analysis (MOOSRA) methods to handle the laptop selection problem. Gou et al. [45] developed a modified MULTIMOORA method based on double hierarchy linguistic term sets to select the optimal city in China.

III. PRELIMINARIES

Some basic concepts and operational rules on IVIULSs [13] are recalled in this section.

Definition 1: Let X be a given domain and $\tilde{s}_x \in \tilde{S}$, then an IVIULS is denoted by

$$\tilde{A}=\left\{< x\left(\tilde{s}_x,\tilde{u}_{\tilde{A}}(x),\tilde{v}_{\tilde{A}}(x)\right)>\right\}, \tag{1}$$

where $\tilde{s}_x=\left[s_{\theta(x)},s_{\tau(x)}\right]$ is regarded as an uncertain linguistic variable; $\theta(x)$ and $\tau(x)$ are the subscripts of the lower limit and upper limit to $\tilde{s}_x$, respectively. The intervals $\tilde{u}_{\tilde{A}}: X \rightarrow D[0,1]$ and $\tilde{v}_{\tilde{A}}: X \rightarrow D[0,1]$ respectively represent the membership degree and non-membership degree of the element x to the uncertain linguistic variable $\tilde{s}_x$ with the constraint $0 \le \sup\left(\tilde{u}_{\tilde{A}}(x)\right)+\sup\left(\tilde{v}_{\tilde{A}}(x)\right) \le 1,\ x \in X$.

For any element $x \in X$, $\tilde{u}_{\tilde{A}}(x)$ and $\tilde{v}_{\tilde{A}}(x)$ are closed intervals and their lower points and upper points are presented as $u_{\tilde{A}}^L(x)$, $u_{\tilde{A}}^U(x)$, $v_{\tilde{A}}^L(x)$ and $v_{\tilde{A}}^U(x)$. Then $\tilde{A}$ can be denoted by

$$\tilde{A}=\left\{\left\langle x\left(\left[s_{\theta(x)},s_{\tau(x)}\right],\left[u_{\tilde{A}}^L(x),u_{\tilde{A}}^U(x)\right],\left[v_{\tilde{A}}^L(x),v_{\tilde{A}}^U(x)\right]\right)\right\rangle \mid x \in X\right\}, \tag{2}$$

where $s_{\theta(x)},s_{\tau(x)} \in S$, $0 \le u_{\tilde{A}}^U(x)+v_{\tilde{A}}^U(x) \le 1$, $u_A^L(x) \ge 0$ and $v_A^L(x) \ge 0$.

For any element $x \in X$, the hesitation interval of the element x to the uncertain linguistic variable $\tilde{s}_x=\left[s_{\theta(x)},s_{\tau(x)}\right]$ is computed as:

$$\tilde{\pi}_{\tilde{A}}(x)=\left[\pi_{\tilde{A}}^L(x),\pi_{\tilde{A}}^U(x)\right]=\left[1-u_{\tilde{A}}^U(x)-v_{\tilde{A}}^U(x),1-u_{\tilde{A}}^L(x)-v_{\tilde{A}}^L(x)\right]. \tag{3}$$

Definition 2: Let $\tilde{A}=\left\{\left\langle x\left(\left[s_{\theta(x)},s_{\tau(x)}\right],\left[u_{\tilde{A}}^L(x),u_{\tilde{A}}^U(x)\right],\left[v_{\tilde{A}}^L(x),v_{\tilde{A}}^U(x)\right]\right)\right\rangle \mid x \in X\right\}$ be an IVIULS, then the 6-tuple $\left\langle\left[s_{\theta(x)},s_{\tau(x)}\right],\left[u_{\tilde{A}}^L(x),u_{\tilde{A}}^U(x)\right],\left[v_{\tilde{A}}^L(x),v_{\tilde{A}}^U(x)\right]\right\rangle$ is called an interval-valued intuitionistic uncertain linguistic number (IVIULN). $\tilde{A}$ can be regarded as a collection of IVIULNs, thus, $\tilde{A}=\left\{\left\langle\left[s_{\theta(x)},s_{\tau(x)}\right],\left[u_{\tilde{A}}^L(x),u_{\tilde{A}}^U(x)\right],\left[v_{\tilde{A}}^L(x),v_{\tilde{A}}^U(x)\right]\right\rangle \mid x \in X\right\}$.

Suppose $\tilde{a}_1=\left\langle\left[s_{\theta(\tilde{a}_1)},s_{\tau(\tilde{a}_1)}\right],\left[u^L(\tilde{a}_1),u^U(\tilde{a}_1)\right],\left[v^L(\tilde{a}_1),v^U(\tilde{a}_1)\right]\right\rangle$ and $\tilde{a}_2=\left\langle\left[s_{\theta(\tilde{a}_2)},s_{\tau(\tilde{a}_2)}\right],\left[u^L(\tilde{a}_2),u^U(\tilde{a}_2)\right],\left[v^L(\tilde{a}_2),v^U(\tilde{a}_2)\right]\right\rangle$ are two IVIULNs and $\lambda \ge 0$, the operational rules of $\tilde{a}_1$ and $\tilde{a}_2$ are given below [46, 47]:

1) $\tilde{a}_1 \oplus \tilde{a}_2=\Big\langle\left[s_{\theta(\tilde{a}_1)+\theta(\tilde{a}_2)},s_{\tau(\tilde{a}_1)+\tau(\tilde{a}_2)}\right],\Big[1-\left(1-u^L(\tilde{a}_1)\right)\left(1-u^L(\tilde{a}_2)\right),$
$1-\left(1-u^U(\tilde{a}_1)\right)\left(1-u^U(\tilde{a}_2)\right)\Big],\left[v^L(\tilde{a}_1)v^L(\tilde{a}_2),v^U(\tilde{a}_1)v^U(\tilde{a}_2)\right]\Big\rangle;$

2) $\tilde{a}_1 \otimes \tilde{a}_2=\Big\langle\left[s_{\theta(\tilde{a}_1)\times\theta(\tilde{a}_2)},s_{\tau(\tilde{a}_1)\times\tau(\tilde{a}_2)}\right],\left[u^L(\tilde{a}_1)u^L(\tilde{a}_2),u^U(\tilde{a}_1)u^U(\tilde{a}_2)\right],$
$\Big[1-\left(1-v^L(\tilde{a}_1)\right)\left(1-v^L(\tilde{a}_2)\right),1-\left(1-v^U(\tilde{a}_1)\right)\left(1-v^U(\tilde{a}_2)\right)\Big]\Big\rangle;$

3) $\lambda\tilde{a}_1=\Big\langle\left[s_{\lambda\times\theta(\tilde{a}_1)},s_{\lambda\times\tau(\tilde{a}_1)}\right],\left[1-\left(1-u^L(\tilde{a}_1)\right)^\lambda,1-\left(1-u^U(\tilde{a}_1)\right)^\lambda\right],$
$\left[\left(v^L(\tilde{a}_1)\right)^\lambda,\left(v^U(\tilde{a}_1)\right)^\lambda\right]\Big\rangle;$

4) $\tilde{a}_1^{\ \lambda}=\Big\langle\left[s_{(\theta(\tilde{a}_1))^\lambda},s_{(\tau(\tilde{a}_1))^\lambda}\right],\left[\left(u^L(\tilde{a}_1)\right)^\lambda,\left(u^U(\tilde{a}_1)\right)^\lambda\right],$
$\left[1-\left(1-v^L(\tilde{a}_1)\right)^\lambda,1-\left(1-v^U(\tilde{a}_1)\right)^\lambda\right]\Big\rangle.$

For the purpose of comparing IVIULNs, the expected value and the accuracy function of an IVIULN are introduced as follows.

Definition 3: Suppose $\tilde{a}_1 = \left\langle \left[s_{\theta(\tilde{a}_1)}, s_{\tau(\tilde{a}_1)} \right], \left[u^L(\tilde{a}_1), u^U(\tilde{a}_1) \right], \left[v^L(\tilde{a}_1), v^U(\tilde{a}_1) \right] \right\rangle$ is an IVIULN, its expected value $E(\tilde{a}_1)$ is computed by [13]:

$$E(\tilde{a}_1) = \frac{1}{2}\left(\frac{u^L(\tilde{a}_1) + u^U(\tilde{a}_1)}{2} + 1 - \left(\frac{v^L(\tilde{a}_1) + v^U(\tilde{a}_1)}{2} \right) \right) \times s_{(\theta(\tilde{a}_1)+\tau(\tilde{a}_1))/2} \quad (4)$$
$$= s_{(\theta(\tilde{a}_1)+\tau(\tilde{a}_1))\times\left(u^L(\tilde{a}_1)) + u^U(\tilde{a}_1) + 2 - v^L(\tilde{a}_1) - v^U(\tilde{a}_1)\right)/8},$$

and the accuracy function $T(\tilde{a}_1)$ of $\tilde{a}_1$ is defined by

$$T(\tilde{a}_1) = s_{(\theta(\tilde{a}_1)+\tau(\tilde{a}_1))/2} \times \left(\frac{u^L(\tilde{a}_1) + u^U(\tilde{a}_1)}{2} + \frac{v^L(\tilde{a}_1) + v^U(\tilde{a}_1)}{2} \right) \quad (5)$$
$$= s_{\left(u^L(\tilde{a}_1) + u^U(\tilde{a}_1) + v^L(\tilde{a}_1) + v^U(\tilde{a}_1)\right)\times(\theta(\tilde{a}_1)+\tau(\tilde{a}_1))/4}.$$

Definition 4: Let

$\tilde{a}_1 = \left\langle \left[s_{\theta(\tilde{a}_1)}, s_{\tau(\tilde{a}_1)} \right], \left[u^L(\tilde{a}_1), u^U(\tilde{a}_1) \right], \left[v^L(\tilde{a}_1), v^U(\tilde{a}_1) \right] \right\rangle$,

$\tilde{a}_2 = \left\langle \left[s_{\theta(\tilde{a}_2)}, s_{\tau(\tilde{a}_2)} \right], \left[u^L(\tilde{a}_2), u^U(\tilde{a}_2) \right], \left[v^L(\tilde{a}_2), v^U(\tilde{a}_2) \right] \right\rangle$

are two IVIULNs. The comparison rules of IVIULNs are defined as follows [48]:

1) If $E(\tilde{a}_1) > E(\tilde{a}_2)$, then $\tilde{a}_1 > \tilde{a}_2$;
2) If $E(\tilde{a}_2) = E(\tilde{a}_2)$, then
    (a) if $T(\tilde{a}_1) > T(\tilde{a}_2)$, then $\tilde{a}_1 > \tilde{a}_2$;
    (b) if $T(\tilde{a}_1) = T(\tilde{a}_2)$, then $\tilde{a}_1 = \tilde{a}_2$.

To aggregate uncertain linguistic information, the interval-valued intuitionistic uncertain linguistic weighted average (IVIULWA) operator is proposed by Liu [13].

Definition 5: Let

$\tilde{a}_i = \left\langle \left[s_{\theta(\tilde{a}_i)}, s_{\tau(\tilde{a}_i)} \right], \left[u^L(\tilde{a}_i), u^U(\tilde{a}_i) \right], \left[v^L(\tilde{a}_i), v^U(\tilde{a}_i) \right] \right\rangle$ $(i = 1, 2, ..., n)$ be a collection of IVIULNs, then the IVIULWA operator is defined as

$$\text{IVIULWA}(\tilde{a}_1, \tilde{a}_2, ..., \tilde{a}_n) = \sum_{j=1}^{n} w_j \tilde{a}_j, \quad (6)$$

where $w = (w_1, w_2, ..., w_n)^T$ is the associated weight vector of $\tilde{a}_j$ $(j = 1, 2, ..., n)$, which satisfies $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$.

Definition 6: Suppose

$\tilde{a}_1 = \left\langle \left[s_{\theta(\tilde{a}_1)}, s_{\tau(\tilde{a}_1)} \right], \left[u^L(\tilde{a}_1), u^U(\tilde{a}_1) \right], \left[v^L(\tilde{a}_1), v^U(\tilde{a}_1) \right] \right\rangle$,

$\tilde{a}_2 = \left\langle \left[s_{\theta(\tilde{a}_2)}, s_{\tau(\tilde{a}_2)} \right], \left[u^L(\tilde{a}_2), u^U(\tilde{a}_2) \right], \left[v^L(\tilde{a}_2), v^U(\tilde{a}_2) \right] \right\rangle$

are two IVIULNs. The Hamming distance between $\tilde{a}_1$ and $\tilde{a}_2$ is defined as:

$$d(\tilde{a}_1, \tilde{a}_2) = \frac{1}{6}\left(\begin{array}{l} \left(\left| \theta(\tilde{a}_1) - \theta(\tilde{a}_2) \right| + \left| \tau(\tilde{a}_1) - \tau(\tilde{a}_2) \right| \right)/9 + \left| u^L(\tilde{a}_1) - u^L(\tilde{a}_2) \right| \\ + \left| u^U(\tilde{a}_1) - u^U(\tilde{a}_2) \right| + \left| v^L(\tilde{a}_1) - v^L(\tilde{a}_2) \right| + \left| v^U(\tilde{a}_1) - v^U(\tilde{a}_2) \right| \end{array} \right). \quad (7)$$

IV. THE PROPOSED GREEN SUPPLIER SELECTION MODEL

This section develops a hybrid MCDM approach for selecting most appropriate green suppliers under the large group environment. In the proposed model, decision makers are clustered by employing an ant colony algorithm; assessment values of clusters are aggregated by the IVIULWA operator; criteria weights are computed by the LINMAP method; the alternative suppliers are ranked finally based on a modified MULTIMOORA approach. The flowchart of the green supplier selection method being proposed is shown in Figure 1.

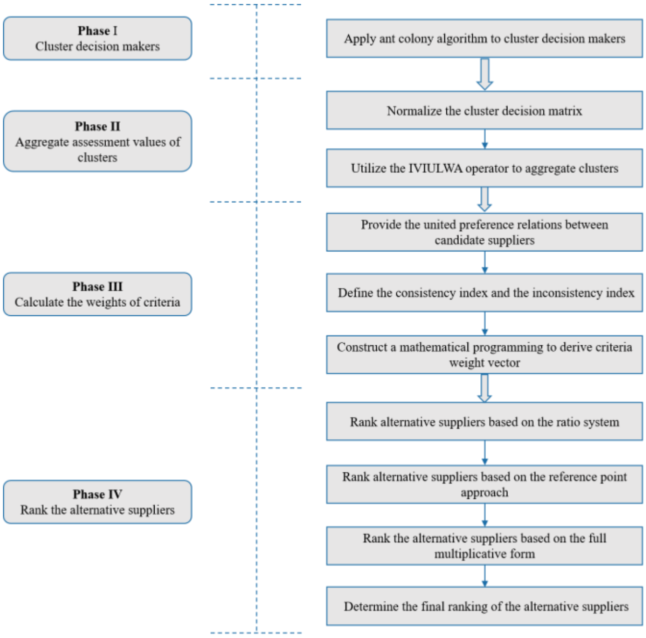

FIGURE 1. **Schematic diagram of the proposed model.**

For a green supplier selection problem with m alternatives A_i $(i = 1, 2, ..., m)$, n criteria C_j $(j = 1, 2, ..., n)$, and L decision makers DM_k $(k = 1, 2, ..., L; L > 20)$, the evaluation matrix by the kth decision maker is denoted as $\tilde{P}^k = \left[\tilde{p}_{ij}^k \right]_{m\times n}$, where $\tilde{p}_{ij}^k = \left\langle \left[s_{a_{ijk}^L}, s_{a_{ijk}^U} \right], \left[u_{ijk}^L, u_{ijk}^U \right], \left[v_{ijk}^L, v_{ijk}^U \right] \right\rangle$ is the IVIULN given by DM_k for the alternative supplier A_i on the criterion C_j, with the condition $0 \le u_{ijk}^L \le 1$, $0 \le v_{ijk}^L \le 1$, $u_{ijk}^U + v_{ijk}^U \le 1$, $u_{ijk}^L \le u_{ijk}^U$, $v_{ijk}^L \le v_{ijk}^U$, $s_{a_{ijk}^L}, s_{a_{ijk}^U} \in S$. Next, the procedure of the proposed green supplier selection approach is explained in the following subsections.

B. CLUSTER DECISION MAKERS

Ant colony algorithm is an effective clustering method inspired by the foraging behavior of ant colony. Real ants can choose the shortest route between their nest and food source. Ants will leave the pheromone in the path and can be aware of the existence and strength of pheromone during the course of movement. The larger the number of ants pass through a given path, the more pheromone the path

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accumulates [49]. In turn, the number of ants choosing the path will increase with a positive feedback effect [50]. Finally, the ants will find the shortest path. In this algorithm, the clustering center is “food source”. The clustering process can be viewed as the process of ants looking for the “food source”. Ant colony algorithm is a promising method for data classification, which intend to discover a list of classification rules (Liang et al., 2016).

In this paper, we cluster decision makers by using the ant colony algorithm. For each supplier $A_i\left(i=1,2,...,m\right)$, the L decision makers $\mathrm{DM}_k\left(k=1,2,...,L\right)$ can be clustered into m clustering results based on their evaluations. The algorithm under the IVIUL environment is expressed as below:

1) Transform all the IVIULNs into expected values as input data.
2) Set parameters: the number of clusters *g*, the number of ants *f*, the maximum number of iterations $t_{\max}$, pheromone threshold *q*, and evaporation rate ε.
3) Initialize the pheromone matrix $\Pi_{L\times g}$. The initial value of each element in $\Pi_{L\times g}$ is 0.01.
4) Determine ants’ path according to the value in pheromone matrix $\Pi_{L\times g}$. If all the pheromone values of a sample are less than the pheromone threshold *q*, then the cluster corresponding to the largest pheromone is selected. If the pheromone values are greater than the pheromone threshold *q*, the cluster is determined based on the proportion of pheromone in each path of total pheromones.
5) Identify the cluster centers on all criteria of each cluster. The cluster center is the average of all samples in the cluster with respect to each criterion.
6) Compute the sum of the Euclidean distances (deviation error) of each ant from each sample to its corresponding cluster center, and select the path corresponding to the smallest deviation error as the best path for this iteration. The smaller the deviation error, the better the clustering effect.
7) Update pheromone matrix $\Pi_{L\times g}$ .The updated value is the original pheromone value multiply $\left(1-\varepsilon\right)$ and plus the reciprocal of the minimum deviation error. Choose the best path according to the new pheromone matrix and perform iteration operations until reach the maximum number of iterations $t_{\max}$.

B. AGGREGATE CLUSTERS

Suppose $G^z\left(z=1,2,...,g\right)$ is the *z*th cluster and l_z is the number of decision makers in G^z, with the condition $\sum_{z=1}^{g} l_z = L$. The evaluation for the supplier A_i with respect to the criterion C_j of the cluster G^z is the average of the assessments given by decision makers, i.e.,

$$\begin{aligned}\tilde{p}_{ij}^{z} &= \left\langle \left[s_{a_{ijz}^{L}}, s_{a_{ijz}^{U}} \right], \left[u_{ijz}^{L}, u_{ijz}^{U} \right], \left[v_{ijz}^{L}, v_{ijz}^{U} \right] \right\rangle \\ &= \left\langle \left[s_{\frac{1}{l_z}\sum\limits_{k\in G_z} a_{ijk}^{L}}, s_{\frac{1}{l_z}\sum\limits_{k\in G_z} a_{ijk}^{U}} \right], \left[\frac{1}{l_z}\sum_{k\in G_z} u_{ijk}^{L}, \frac{1}{l_z}\sum_{k\in G_z} u_{ijk}^{U} \right], \left[\frac{1}{l_z}\sum_{k\in G_z} v_{ijk}^{L}, \frac{1}{l_z}\sum_{k\in G_z} v_{ijk}^{U} \right] \right\rangle, \end{aligned} \tag{8}$$

$$i=1,2,...,m,\ j=1,2,...,n, z=1,2,...,g.$$

To eliminate the effects of different dimensions and ensure the compatibility of IVIULNs with respect to all criteria, we normalize the cluster decision matrix $\tilde{P}^z = \left[\tilde{p}_{ij}^{z}\right]_{m\times n}$ by using the following formulas:

$$\tilde{r}_{ij}^{z} = \left\langle \left[s_{a_{ijz}^{L}/a_{j\max}^{U}}, s_{a_{ijz}^{U}/a_{j\max}^{U}} \right], \left[u_{ijz}^{L}, u_{ijz}^{U} \right], \left[v_{ijz}^{L}, v_{ijz}^{U} \right] \right\rangle, \left(j\in J_1\right), \tag{9}$$

$$\tilde{r}_{ij}^{z} = \left\langle \left[s_{\left(1-a_{ijz}^{U}\right)/a_{j\max}^{U}}, s_{\left(1-a_{ijz}^{L}\right)/a_{j\max}^{U}} \right], \left[v_{ijz}^{L}, v_{ijz}^{U} \right], \left[u_{ijz}^{L}, u_{ijz}^{U} \right] \right\rangle, \left(j\in J_2\right), \tag{10}$$

$$i=1,2,...,m,\ j=1,2,...,n, z=1,2,...g,$$

where J_1 and J_2 denote the sets of benefit criteria and cost criteria, respectively, and $a_{j\max}^{U} = \max\left(a_{ijz}^{U}, i=1,2,...,m, z=1,2,...,g\right)$.

Generally, the cluster with more decision makers should be given a bigger weight. Thus, the weight of each cluster $G^z\left(z=1,2,...,g\right)$ can be calculated by

$$\lambda_z = \frac{l_z}{L},\quad z=1,2,...,g. \tag{11}$$

Then, we adopt the IVIULWA operator to obtain the group normalized decision matrix $\tilde{R}=\left[\tilde{r}_{ij}\right]_{m\times n}$, where $\tilde{r}_{ij}$ is determined by

$$\begin{aligned}\tilde{r}_{ij} &= \mathrm{IVIULWA}(\tilde{r}_{ij}^{1}, \tilde{r}_{ij}^{2}, ..., \tilde{r}_{ij}^{g}) = \sum_{z=1}^{g} \lambda_z \tilde{r}_{ij}^{z} \\ &= \left\langle \left[s_{\sum\limits_{z=1}^{l} \lambda_z a_{ijz}^{L}}, s_{\sum\limits_{z=1}^{l} \lambda_z a_{ijz}^{L}} \right], \left[1-\prod_{z=1}^{g}\left(1-u_{ijz}^{L}\right)^{\lambda_z}, 1-\prod_{k=1}^{l}\left(1-u_{ijz}^{U}\right)^{\lambda_z} \right], \left[\prod_{z=1}^{g}\left(v_{ijz}^{L}\right)^{\lambda_z}, \prod_{z=1}^{g}\left(v_{ijz}^{U}\right)^{\lambda_z} \right] \right\rangle, \end{aligned} \tag{12}$$

$$i=1,2,...,m,\ j=1,2,...,n,$$

where λ_z is the associated weight of $\tilde{r}_{ij}^{z} = \left\langle \left[s_{a_{ijz}^{L}}, s_{a_{ijz}^{U}} \right], \left[u_{ijz}^{L}, u_{ijz}^{U} \right], \left[v_{ijz}^{L}, v_{ijz}^{U} \right] \right\rangle$ $\left(z=1,2,...,g\right)$, with the condition $\lambda_z\in[0,1]$ and $\sum_{z=1}^{g}\lambda_z = 1$.

C. CALCULATE THE WEIGHTS OF CRITERIA

The LINMAP is a classical and effective MCDM method proposed by Srinivasan and Shocker [51]. It is can be used for computing the objective criteria weights by establishing a mathematical programming [52]. Therefore, in this study, we extend the LINMAP method to the IVIUL context for deriving the weight vector of criteria. The specific steps are given below:

Step 1: The decision makers give the united preference relations between the candidate suppliers $\Omega=\left\{\left(A_h, A_i\right)\middle| A_h \geq A_i, \left(h,i=1,2,...,m\right)\right\}$.

The decision makers provide the corresponding pairwise comparisons of the candidate suppliers as a whole. The priority relations between alternatives are determined by overall judgement rather than on each criterion.

Step 2: Define the consistency index and inconsistency index between objective ranking order and subjective preference relation.

The IVIULN ideal solution (reference point) on each criterion are represented as $r^* = \left(r_1^*, r_2^*, ..., r_n^*\right)$, where $r_j^* = \left\langle \left[s_{a_j^L}, s_{a_j^U}\right], \left[u_j^L, u_j^U\right], \left[v_j^L, v_j^U\right] \right\rangle \left(j = 1, 2, ..., n\right)$ is the best rating on the criterion C_j. Then the Hamming distance between each alternative of $\left(A_h, A_i\right) \in \Omega$ and ideal solution r^* is calculated by

$$D_h = \sum_{j=1}^{n} w_j d\left(\tilde{r}_{hj}, \tilde{r}_j^*\right), \tag{13}$$

$$D_i = \sum_{j=1}^{n} w_j d\left(\tilde{r}_{ij}, \tilde{r}_j^*\right), \tag{14}$$

where $w = \left(w_1, w_2, ..., w_n\right)$ is the criteria weight vector.

For each pair of the alternative suppliers $\left(A_h, A_i\right) \in \Omega$, the decision makers prefer supplier A_h to A_i or make no difference between A_h and A_i. Thus, if $D_i \geq D_h$, the ranking order determined by D_i and D_h is consistent with the preference relation by decision makers. Otherwise, if $D_i < D_h$, then the ranking order determined by D_i and D_h is inconsistent with the preference relation by decision makers. Accordingly, the indexes $\left(D_i - D_h\right)^+$ and $\left(D_i - D_h\right)^-$ are respectively used to measure consistency and inconsistency between the objective ranking orders determined by D_i, D_h and subjective preference relation [53, 54].

$$\left(D_i - D_h\right)^+ = \max\left\{0, \left(D_i - D_h\right)\right\}, \tag{15}$$

$$\left(D_i - D_h\right)^- = \max\left\{0, \left(D_h - D_i\right)\right\}. \tag{16}$$

Hence, the total consistency index and inconsistency index of all pairs of suppliers can be calculated by the following equations:

$$H = \sum_{(h,i)\in\Omega} \left(D_i - D_h\right)^+ = \sum_{(h,i)\in\Omega} \max\left\{0, D_i - D_h\right\}, \tag{17}$$

$$B = \sum_{(h,i)\in\Omega} \left(D_i - D_h\right)^- = \sum_{(h,i)\in\Omega} \max\left\{0, D_h - D_i\right\}. \tag{18}$$

Step 3: Construct a mathematical programming to derive the criteria weight vector.

Let $Z_{hi} = \max\left\{0, D_h - D_i\right\}$ for each pair $\left(A_h, A_i\right) \in \Omega$, with the condition $Z_{hi} \geq 0$. Then $Z_{hi} \geq D_h - D_i$ is obtained. Since the total inconsistency index B reflects the group inconsistency between the objective ranking order and subjective preference relations, then B should be minimized. Therefore, we can construct a mathematical programming as follows:

$$\min\left\{\sum_{(h,i)\in\Omega} Z_{hi}\right\}$$
$$s.t.\left\{\begin{array}{l} \sum_{(h,i)\in\Omega} \left(D_i - D_h\right)^+ - \sum_{(h,i)\in\Omega} \left(D_i - D_h\right)^- \geq \mu, \\ Z_{hi} + D_h - D_i \geq 0, \\ Z_{hi} \geq 0, \\ \sum_{j=1}^{n} w_j = 1, \\ w_j \geq \delta, \ \left(j = 1, 2, ..., n\right) \end{array}\right. \tag{19}$$

where $\mu > 0$ is used to ensure the total consistency index H bigger or equal to the inconsistency index B, and $\delta > 0$ can ensure the weight of each crterion greater than 0.

D. RANK THE ALTERNATIVE SUPPLIERS

After obtaining the group normalized evaluations of suppliers in the second stage, we utilize a modified MULTIMOORA method to rank the alternative suppliers in this subsection. The ranking process is presented as below.

Step 1: Rank alternative suppliers based on the ratio system approach.

The evaluation values of ratio system is obtained by adding the normalized ratings on all the criteria of each supplier, i.e.,

$$\tilde{\gamma}_i = \sum_{j=1}^{n} w_j \tilde{r}_{ij}, \quad i = 1, 2, ..., m, \tag{20}$$

where $\tilde{\gamma}_i$ represents the overall evaluation value of A_i with regard to all the criteria. The ranking of the alternative suppliers are determined by the values $\tilde{\gamma}_i \left(i = 1, 2, ..., m\right)$ in descending order.

Step 2: Rank alternative suppliers by the reference point approach.

In the third phase, we have determined the ieal solution as the best rating. Then the weighted distance of each supplier to the ieal solution is computed by

$$d_i = \sum_{j=1}^{n} w_j d\left(\tilde{r}_{ij}, \tilde{r}_j^*\right), \quad i = 1, 2, ..., m. \tag{21}$$

The alternative suppliers are ranked based on distances $d_i \left(i = 1, 2, ..., m\right)$ in increasing order.

Step 3: Rank alternative suppliers based on the full multiplicative form approach.

The overall utility of each supplier can be represented as an IVIULN by

$$\tilde{U}_i = \prod_{j=1}^{n} w_j \tilde{r}_{ij}, \quad i = 1, 2, ..., m. \tag{22}$$

The green suppliers are ranked according to the values $\tilde{U}_i \left(i = 1, 2, ..., m\right)$ in descending order.

Step 4: Determine the final ranking of alternative suppliers.

By utilizing the theory of dominance, we can integrate the three rankings acquired by the ratio system, the reference point and the full multiplicative form to determine the final ranking of the *m* green suppliers.

V. CASE STUDY

A. IMPLEMENTATION

This section applies the proposed model to select the optimal timber green supplier for a real estate company in Shanghai, China. The related research data show that the carbon produced by the real estate industry in China accounted for about eight percent of global carbon emissions. As facing the great opportunity of green tranformation, Alashan SEE ecological association, China urban real estate developers strategic alliance, all real estate association, Vanke enterprise and Landsea green real estate co-sponsored the action of green supply chain in the real estate industry on June 5, 2016. The white lists of qualtified suppliers are determined by real estate companies participating in the green supply chain action according to green standards, which include steel suppliers, cement suppliers, timber suppliers and aluminum suppliers. This study aims to assisst the real estate company to find out the most appropriate timber supplier.

After initial screening, four suppliers $\left(A_i, i=1,2,\ldots,4\right)$ are remained for further assessment and selection. Based on a literature review and expert interviews, five evaluation criteria $\left(C_j, j=1,2,\ldots,5\right)$, product quality, purchase cost, technology capability, green degree and delivery level (Liao, Fu, & Wu, 2016), are identified for the green supplier selection. Besides, an expert group consisting of twenty-two decision makers, $\left(\mathrm{DM}_k, k=1,2,\ldots,22\right)$, is invited to evaluation the performance of the four alternative suppliers with respect to each criterion. The linguistic terms set *S* is used in the performance evaluation of the suppliers.

$$S=\{s_0=very\ \ poor,\ s_1=poor,\ s_2=medium\ poor,\ s_3=\ fair,$$
$$s_4=medium\ \ good,\ s_5=good,\ s_6=very\ \ good\}.$$

The assessments of the four alternative suppliers on the five crieria provided by all the decision makers are shown in Tables 1-4. First, we transform the IVIULNs into their expected values as input data. Then the parameters of the ant colony algorithm are set as: the number of clusters $g=5$, the number of ants $f=1000$, the maximum number of iterations $t_{\max}=1000$, pheromone threshold $q=0.9$, and evaporation rate $\varepsilon=0.1$. By using the ant colony algorithm, the clustering results of decision makers are shown in Table 5.

Based on Equation (8), the evaluation values for the four suppliers of the five clusters are calculated as shown in Table 6. Next the evaluation values of the five clusters are normalize by utilizing Equations (9)-(10), and the results are shown in Table 7. By Equation (12), the normalized evaluations of the five clusters are aggregated into the collective normalized evaluation matrix $\tilde{R}=\left[\tilde{r}_{ij}\right]_{4\times5}$ as shown in Table 8.

The united preference relations of the candidate suppliers given by the twenty-two decision makers are: $\Omega=\{(1,3),(2,1),(2,4),(1,4)\}$. The ideal solution is set as $\langle[s_1,s_1],[1,1],[0,0]\rangle$ for each criterion. Then the following linear programming is eatablished to calculate the weights of criteria:

$$\min Z_{13}+Z_{21}+Z_{24}+Z_{14}$$
$$s.t.\begin{cases}0.839w_1-0.768w_2+2.792w_3+1.117w_4+0.924w_5\geq1,\\0.019w_1+0.229w_2+0.574w_3+0.057w_4+0.130w_5+Z_{13}\geq0,\\0.252w_1-0.664w_2+0.537w_3+0.231w_4+0.133w_5+Z_{21}\geq0,\\0.273w_1-0.282w_2+0.553w_3+0.386w_4+0.265w_5+Z_{24}\geq0,\\0.294w_1-0.052w_2+1.127w_3+0.443w_4+0.395w_5+Z_{14}\geq0,\\w_j\geq0.01,(j=1,2,\ldots,5),\\w_1+w_2+w_3+w_4+w_5=1.\end{cases}$$

By solving the above model, the weights of the five criteria is derived as $w=(0.28,0.10,0.10,0.42,0.10)$.

In the fourth stage, the modified MULTIMOORA method is used to rank the four timber green suppliers. Firstly, based on the ratio system approach, the ranking order of the alternative suplliers are determined by Equation (20), and the result is:

$$\tilde{\gamma}_1=\langle[s_{0.687},s_{0.803}],[0.608,0.742],[0.099,0.206]\rangle,$$
$$\tilde{\gamma}_2=\langle[s_{0.698},s_{0.810}],[0.910,0.953],[0.000,0.000]\rangle,$$
$$\tilde{\gamma}_3=\langle[s_{0.597},s_{0.736}],[0.599,0.734],[0.122,0.229]\rangle,$$
$$\tilde{\gamma}_4=\langle[s_{0.588},s_{0.725}],[0.576,0.717],[0.146,0.241]\rangle.$$

Based on the comparison rules of IVIULNs in Definition 4, the ranking of the four suppliers is derived as $A_2> A_1> A_3> A_4$.

Secondly, in accordance with the reference point approach, the weighted distance of each supplier to the ideal solution is computed by Equation (21), and the result is:

$$d_1=1.581, d_2=1.458, d_3=1.750, d_4=1.874.$$

Thus, the four timber supplilers are ranked as $A_2> A_1> A_3> A_4$.

Thirdly, according to the the full multiplicative form approach, the overall utility value of each supplier is determined by Equation (22).

$$\tilde{U}_1=\langle[s_{6.966*10^{-6}},s_{2.049*10^{-5}}],[8.472*10^{-6},6.566*10^{-5}],[0.999,0.999]\rangle,$$
$$\tilde{U}_2=\langle[s_{1.168*10^{-5}},s_{2.947*10^{-5}}],[9.033*10^{-5},4.075*10^{-4}],[0.997,0.999]\rangle,$$
$$\tilde{U}_3=\langle[s_{4.783*10^{-6}},s_{1.487*10^{-5}}],[1.834*10^{-5},9.952*10^{-5}],[0.999,0.999]\rangle,$$
$$\tilde{U}_4=\langle[s_{5.213*10^{-6}},s_{1.716*10^{-5}}],[5.696*10^{-6},5.342*10^{-5}],[0.999,0.999]\rangle.$$

As a reslult, the ranking of the four suppliers is derived as $A_2> A_1> A_3> A_4$.

To summarize, the final ranking of the four timber suppliers is $A_2> A_1> A_3> A_4$ based on the dominance theory. Therefore, A_2 is the optimum green supplier among the four alternatives for the considered application.

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TABLE 1
PERFORMANCE VALUES OF THE FIRST SUPPLIER A_1 BY THE DECISION MAKERS

Decision makers	Criteria				
	C_1	C_2	C_3	C_4	C_5
DM$_1$	$\langle [s_5,s_6],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_5],[0.6,0.7],[0.1,0.2]\rangle$	$\langle [s_5,s_6],[0.8,0.9],[0.1,0.1]\rangle$	$\langle [s_4,s_4],[0.5,0.6],[0.1,0.3]\rangle$	$\langle [s_5,s_6],[0.8,0.8],[0.1,0.2]\rangle$
DM$_2$	$\langle [s_3,s_4],[0.4,0.5],[0.2,0.3]\rangle$	$\langle [s_4,s_5],[0.6,0.8],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.5,0.7],[0.1,0.2]\rangle$	$\langle [s_4,s_5],[0.6,0.8],[0.0,0.2]\rangle$	$\langle [s_5,s_6],[0.7,0.7],[0.1,0.2]\rangle$
DM$_3$	$\langle [s_4,s_5],[0.6,0.6],[0.1,0.3]\rangle$	$\langle [s_5,s_6],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_5,s_5],[0.7,0.9],[0.0,0.1]\rangle$	$\langle [s_3,s_4],[0.6,0.7],[0.0,0.2]\rangle$	$\langle [s_4,s_5],[0.5,0.6],[0.1,0.2]\rangle$
...	…	…	…	…	…
DM$_{21}$	$\langle [s_6,s_6],[0.7,0.9],[0.1,0.1]\rangle$	$\langle [s_4,s_5],[0.7,0.9],[0.1,0.1]\rangle$	$\langle [s_5,s_6],[0.7,0.8],[0.1,0.1]\rangle$	$\langle [s_4,s_5],[0.6,0.7],[0.1,0.2]\rangle$	$\langle [s_5,s_6],[0.6,0.7],[0.1,0.3]\rangle$
DM$_{22}$	$\langle [s_4,s_5],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_5,s_6],[0.7,0.8],[0.0,0.1]\rangle$	$\langle [s_5,s_6],[0.6,0.7],[0.1,0.2]\rangle$	$\langle [s_4,s_4],[0.7,0.7],[0.1,0.2]\rangle$	$\langle [s_2,s_3],[0.7,0.9],[0.1,0.1]\rangle$

TABLE 2
PERFORMANCE VALUES OF THE SECOND SUPPLIER A_2 BY THE DECISION MAKERS

Decision makers	Criteria				
	C_1	C_2	C_3	C_4	C_5
DM$_1$	$\langle [s_6,s_6],[0.6,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_5],[0.5,0.7],[0.1,0.3]\rangle$	$\langle [s_4,s_5],[0.8,0.8],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.5,0.6],[0.1,0.2]\rangle$	$\langle [s_4,s_5],[0.6,0.8],[0.1,0.2]\rangle$
DM$_2$	$\langle [s_5,s_6],[0.7,0.8],[0.2,0.2]\rangle$	$\langle [s_5,s_5],[0.6,0.7],[0.1,0.2]\rangle$	$\langle [s_5,s_6],[0.7,0.7],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.5,0.7],[0.0,0.2]\rangle$	$\langle [s_4,s_5],[0.5,0.6],[0.2,0.3]\rangle$
DM$_3$	$\langle [s_5,s_6],[0.6,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_5],[0.6,0.7],[0.2,0.3]\rangle$	$\langle [s_3,s_4],[0.8,0.9],[0.0,0.1]\rangle$	$\langle [s_4,s_4],[0.5,0.7],[0.1,0.2]\rangle$	$\langle [s_4,s_5],[0.8,0.9],[0.1,0.1]\rangle$
…	…	…	…	…	…
DM$_{21}$	$\langle [s_4,s_5],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_4],[0.6,0.9],[0.0,0.1]\rangle$	$\langle [s_4,s_5],[0.6,0.7],[0.1,0.1]\rangle$	$\langle [s_3,s_4],[0.8,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_4],[0.7,0.7],[0.1,0.3]\rangle$
DM$_{22}$	$\langle [s_4,s_5],[0.7,0.8],[0.1,0.1]\rangle$	$\langle [s_5,s_6],[0.8,0.9],[0.0,0.1]\rangle$	$\langle [s_6,s_6],[0.6,0.8],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.5,0.7],[0.1,0.3]\rangle$	$\langle [s_5,s_6],[0.6,0.8],[0.0,0.2]\rangle$

TABLE 3
PERFORMANCE VALUES OF THE THIRD SUPPLIERA_3 BY THE DECISION MAKERS

Decision makers	Criteria				
	C_1	C_2	C_3	C_4	C_5
DM$_1$	$\langle [s_4,s_5],[0.6,0.7],[0.1,0.3]\rangle$	$\langle [s_5,s_5],[0.5,0.6],[0.2,0.3]\rangle$	$\langle [s_4,s_5],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_5],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.6,0.7],[0.1,0.2]\rangle$
DM$_2$	$\langle [s_5,s_6],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_4],[0.8,0.9],[0.1,0.1]\rangle$	$\langle [s_5,s_6],[0.6,0.7],[0.1,0.2]\rangle$	$\langle [s_5,s_6],[0.5,0.7],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.5,0.6],[0.3,0.4]\rangle$
DM$_3$	$\langle [s_4,s_5],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_4],[0.6,0.7],[0.2,0.2]\rangle$	$\langle [s_3,s_3],[0.7,0.8],[0.0,0.1]\rangle$	$\langle [s_3,s_4],[0.6,0.8],[0.1,0.2]\rangle$	$\langle [s_2,s_3],[0.8,0.9],[0.0,0.1]\rangle$
…	…	…	…	…	…
DM$_{21}$	$\langle [s_4,s_4],[0.5,0.6],[0.1,0.2]\rangle$	$\langle [s_4,s_5],[0.6,0.8],[0.0,0.1]\rangle$	$\langle [s_3,s_4],[0.6,0.7],[0.2,0.2]\rangle$	$\langle [s_3,s_4],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_2,s_3],[0.6,0.7],[0.1,0.3]\rangle$
DM$_{22}$	$\langle [s_4,s_5],[0.8,0.9],[0.1,0.1]\rangle$	$\langle [s_5,s_5],[0.8,0.9],[0.0,0.1]\rangle$	$\langle [s_4,s_5],[0.7,0.8],[0.1,0.2]\rangle$	$\langle [s_5,s_6],[0.5,0.7],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.6,0.8],[0.1,0.2]\rangle$

TABLE 4
PERFORMANCE VALUES OF THE FOURTH SUPPLIERA_4 BY THE DECISION MAKERS

Decision makers	Criteria				
	C_1	C_2	C_3	C_4	C_5
DM$_1$	$\langle [s_5,s_6],[0.6,0.6],[0.1,0.3]\rangle$	$\langle [s_4,s_5],[0.5,0.6],[0.2,0.4]\rangle$	$\langle [s_3,s_4],[0.7,0.7],[0.1,0.2]\rangle$	$\langle [s_5,s_5],[0.6,0.8],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.6,0.7],[0.1,0.3]\rangle$
DM$_2$	$\langle [s_4,s_5],[0.8,0.8],[0.1,0.2]\rangle$	$\langle [s_4,s_4],[0.6,0.7],[0.0,0.1]\rangle$	$\langle [s_3,s_4],[0.5,0.7],[0.2,0.2]\rangle$	$\langle [s_4,s_5],[0.5,0.6],[0.1,0.3]\rangle$	$\langle [s_3,s_4],[0.6,0.7],[0.3,0.3]\rangle$
DM$_3$	$\langle [s_3,s_4],[0.7,0.9],[0.1,0.1]\rangle$	$\langle [s_4,s_5],[0.6,0.8],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.7,0.8],[0.0,0.2]\rangle$	$\langle [s_4,s_5],[0.5,0.6],[0.1,0.3]\rangle$	$\langle [s_2,s_3],[0.7,0.7],[0.0,0.1]\rangle$
…	…	…	…	…	…
DM$_{21}$	$\langle [s_3,s_4],[0.5,0.6],[0.3,0.3]\rangle$	$\langle [s_2,s_3],[0.6,0.8],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.6,0.7],[0.2,0.3]\rangle$	$\langle [s_3,s_3],[0.7,0.7],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.6,0.9],[0.1,0.1]\rangle$
DM$_{22}$	$\langle [s_4,s_5],[0.6,0.8],[0.0,0.1]\rangle$	$\langle [s_5,s_5],[0.6,0.8],[0.0,0.2]\rangle$	$\langle [s_4,s_5],[0.7,0.7],[0.1,0.2]\rangle$	$\langle [s_3,s_4],[0.5,0.7],[0.2,0.3]\rangle$	$\langle [s_4,s_4],[0.5,0.7],[0.2,0.3]\rangle$

TABLE 5

CLUSTERING RESULTS OF THE FOUR SUPPLIERS.

Suppliers	Clusters				
	G^1	G^2	G^3	G^4	G^5
A_1	DM_1, DM_6, DM_7, DM_9, DM_{11}, DM_{19}, DM_{21}	DM_2, DM_{10}, DM_{14}, DM_{15}, DM_{16}, DM_{18}	DM_5, DM_8, DM_{13}, DM_{20},	DM_4, DM_{12}, DM_{17}	DM_3, DM_{22}
A_2	DM_1, DM_2, DM_3, DM_5, DM_6, DM_{15}, DM_{16}, DM_{21}	DM_4, DM_7, DM_8, DM_9, DM_{22}	DM_{10}, DM_{11}, DM_{14}, DM_{17}, DM_{18}	DM_{12}, DM_{13}, DM_{20}	DM_{19}
A_3	DM_1, DM_2, DM_6, DM_{12}, DM_{15}, DM_{17}	DM_4, DM_5, DM_9, DM_{10}, DM_{11}, DM_{16}	DM_7, DM_8, DM_{13}, DM_{19}, DM_{22}	DM_3, DM_{14}, DM_{20}, DM_{21}	DM_{18}
A_4	DM_1, DM_2, DM_5, DM_6, DM_{13}, DM_{17}	DM_4, DM_7, DM_9, DM_{10}, DM_{12}, DM_{16}	DM_3, DM_{11}, DM_{14}, DM_{19}	DM_{18}, DM_{20}, DM_{21}	DM_8, DM_{15}, DM_{22}

TABLE 6

EVALUATION VALUES BY THE FIVE CLUSTERS

Suppliers	Clusters	Criteria				
		C_1	C_2	C_3	C_4	C_5
A_1	G^1	$\langle [s_{5.142}, s_{5.571}], [0.671, 0.829], [0.086, 0.157] \rangle$	$\langle [s_{3.857}, s_{4.714}], [0.586, 0.729], [0.114, 0.186] \rangle$	$\langle [s_{4.857}, s_{5.571}], [0.714, 0.842], [0.071, 0.129] \rangle$	$\langle [s_{4.000}, s_{4.714}], [0.600, 0.757], [0.071, 0.200] \rangle$	$\langle [s_{4.000}, s_{4.714}], [0.629, 0.757], [0.114, 0.200] \rangle$
	G^2	$\langle [s_{3.500}, s_{4.333}], [0.550, 0.700], [0.150, 0.233] \rangle$	$\langle [s_{3.833}, s_{4.333}], [0.633, 0.767], [0.083, 0.183] \rangle$	$\langle [s_{3.833}, s_{4.833}], [0.567, 0.783], [0.133, 0.183] \rangle$	$\langle [s_{3.500}, s_{4.167}], [0.583, 0.733], [0.050, 0.200] \rangle$	$\langle [s_{4.167}, s_{5.167}], [0.650, 0.783], [0.100, 0.167] \rangle$
	G^3	$\langle [s_{5.000}, s_{5.750}], [0.650, 0.800], [0.100, 0.150] \rangle$	$\langle [s_{4.750}, s_{5.500}], [0.650, 0.800], [0.075, 0.175] \rangle$	$\langle [s_{3.750}, s_{4.750}], [0.600, 0.800], [0.075, 0.175] \rangle$	$\langle [s_{3.750}, s_{4.500}], [0.675, 0.775], [0.100, 0.150] \rangle$	$\langle [s_{3.750}, s_{4.500}], [0.575, 0.725], [0.125, 0.225] \rangle$
	G^4	$\langle [s_{4.000}, s_{4.333}], [0.567, 0.767], [0.100, 0.233] \rangle$	$\langle [s_{4.000}, s_{4.667}], [0.600, 0.733], [0.100, 0.200] \rangle$	$\langle [s_{4.667}, s_{5.333}], [0.767, 0.867], [0.067, 0.133] \rangle$	$\langle [s_{5.333}, s_{6.000}], [0.667, 0.767], [0.067, 0.167] \rangle$	$\langle [s_{4.000}, s_{4.000}], [0.567, 0.700], [0.100, 0.200] \rangle$
	G^5	$\langle [s_{4.000}, s_{5.000}], [0.650, 0.700], [0.100, 0.250] \rangle$	$\langle [s_{5.000}, s_{6.000}], [0.700, 0.800], [0.050, 0.150] \rangle$	$\langle [s_{5.000}, s_{5.500}], [0.650, 0.800], [0.050, 0.150] \rangle$	$\langle [s_{3.500}, s_{4.000}], [0.650, 0.700], [0.050, 0.200] \rangle$	$\langle [s_{3.000}, s_{4.000}], [0.600, 0.750], [0.100, 0.150] \rangle$
A_2	G^1	$\langle [s_{4.750}, s_{5.500}], [0.663, 0.788], [0.125, 0.175] \rangle$	$\langle [s_{3.875}, s_{4.500}], [0.575, 0.713], [0.100, 0.213] \rangle$	$\langle [s_{4.125}, s_{5.000}], [0.688, 0.800], [0.088, 0.150] \rangle$	$\langle [s_{3.500}, s_{4.125}], [0.575, 0.725], [0.088, 0.200] \rangle$	$\langle [s_{4.000}, s_{4.875}], [0.663, 0.750], [0.125, 0.225] \rangle$
	G^2	$\langle [s_{5.000}, s_{5.800}], [0.580, 0.780], [0.120, 0.200] \rangle$	$\langle [s_{5.200}, s_{6.000}], [0.700, 0.840], [0.080, 0.140] \rangle$	$\langle [s_{5.000}, s_{5.400}], [0.640, 0.780], [0.100, 0.180] \rangle$	$\langle [s_{4.800}, s_{5.800}], [0.600, 0.780], [0.080, 0.200] \rangle$	$\langle [s_{4.000}, s_{5.000}], [0.650, 0.700], [0.100, 0.250] \rangle$
	G^3	$\langle [s_{3.800}, s_{4.800}], [0.600, 0.760], [0.120, 0.220] \rangle$	$\langle [s_{3.400}, s_{3.800}], [0.620, 0.760], [0.120, 0.200] \rangle$	$\langle [s_{3.200}, s_{4.000}], [0.680, 0.780], [0.140, 0.180] \rangle$	$\langle [s_{2.200}, s_{2.800}], [0.660, 0.760], [0.080, 0.180] \rangle$	$\langle [s_{2.800}, s_{3.800}], [0.660, 0.780], [0.100, 0.200] \rangle$
	G^4	$\langle [s_{4.667}, s_{5.333}], [0.733, 0.800], [0.067, 0.200] \rangle$	$\langle [s_{2.667}, s_{3.667}], [0.667, 0.800], [0.067, 0.167] \rangle$	$\langle [s_{3.000}, s_{4.000}], [0.600, 0.733], [0.100, 0.200] \rangle$	$\langle [s_{4.000}, s_{4.667}], [0.667, 0.833], [0.100, 0.100] \rangle$	$\langle [s_{3.000}, s_{3.667}], [0.600, 0.733], [0.100, 0.267] \rangle$
	G^5	$\langle [s_{3.000}, s_{4.000}], [0.500, 0.700], [0.100, 0.100] \rangle$	$\langle [s_{3.000}, s_{4.000}], [0.600, 0.900], [0.100, 0.100] \rangle$	$\langle [s_{4.000}, s_{5.000}], [0.800, 0.900], [0.000, 0.100] \rangle$	$\langle [s_{5.000}, s_{5.000}], [0.800, 0.900], [0.100, 0.100] \rangle$	$\langle [s_{5.000}, s_{6.000}], [0.800, 0.800], [0.100, 0.200] \rangle$
A_3	G^1	$\langle [s_{4.167}, s_{5.000}], [0.617, 0.700], [0.150, 0.267] \rangle$	$\langle [s_{3.667}, s_{4.167}], [0.633, 0.717], [0.117, 0.200] \rangle$	$\langle [s_{4.333}, s_{5.333}], [0.650, 0.767], [0.083, 0.183] \rangle$	$\langle [s_{4.167}, s_{5.000}], [0.633, 0.800], [0.083, 0.183] \rangle$	$\langle [s_{3.167}, s_{4.167}], [0.600, 0.667], [0.133, 0.283] \rangle$
	G^2	$\langle [s_{4.000}, s_{4.667}], [0.667, 0.783], [0.083, 0.150] \rangle$	$\langle [s_{3.667}, s_{4.667}], [0.550, 0.717], [0.117, 0.267] \rangle$	$\langle [s_{3.333}, s_{3.833}], [0.600, 0.750], [0.100, 0.200] \rangle$	$\langle [s_{3.333}, s_{4.000}], [0.600, 0.733], [0.167, 0.267] \rangle$	$\langle [s_{4.333}, s_{5.333}], [0.650, 0.800], [0.067, 0.167] \rangle$
	G^3	$\langle [s_{3.750}, s_{4.250}], [0.675, 0.750], [0.100, 0.175] \rangle$	$\langle [s_{3.750}, s_{4.500}], [0.625, 0.800], [0.075, 0.150] \rangle$	$\langle [s_{2.750}, s_{3.250}], [0.625, 0.750], [0.100, 0.200] \rangle$	$\langle [s_{2.750}, s_{3.750}], [0.650, 0.775], [0.100, 0.200] \rangle$	$\langle [s_{2.250}, s_{3.250}], [0.625, 0.775], [0.075, 0.200] \rangle$
	G^4	$\langle [s_{4.200}, s_{5.200}], [0.660, 0.760], [0.120, 0.220] \rangle$	$\langle [s_{5.400}, s_{5.800}], [0.700, 0.800], [0.060, 0.140] \rangle$	$\langle [s_{4.200}, s_{5.200}], [0.640, 0.760], [0.100, 0.220] \rangle$	$\langle [s_{4.400}, s_{5.400}], [0.600, 0.760], [0.100, 0.180] \rangle$	$\langle [s_{4.000}, s_{4.800}], [0.600, 0.760], [0.120, 0.240] \rangle$
	G^5	$\langle [s_{2.000}, s_{3.000}], [0.500, 0.600], [0.200, 0.300] \rangle$	$\langle [s_{3.000}, s_{3.000}], [0.700, 0.900], [0.000, 0.100] \rangle$	$\langle [s_{2.000}, s_{2.000}], [0.600, 0.700], [0.100, 0.300] \rangle$	$\langle [s_{2.000}, s_{3.000}], [0.500, 0.800], [0.100, 0.200] \rangle$	$\langle [s_{1.000}, s_{2.000}], [0.700, 0.700], [0.100, 0.300] \rangle$
A_4	G^1	$\langle [s_{4.333}, s_{5.333}], [0.567, 0.700], [0.133, 0.267] \rangle$	$\langle [s_{4.167}, s_{4.500}], [0.533, 0.633], [0.100, 0.267] \rangle$	$\langle [s_{3.167}, s_{4.167}], [0.583, 0.700], [0.133, 0.217] \rangle$	$\langle [s_{4.167}, s_{4.833}], [0.617, 0.767], [0.083, 0.200] \rangle$	$\langle [s_{2.833}, s_{3.833}], [0.633, 0.700], [0.150, 0.267] \rangle$
	G^2	$\langle [s_{4.333}, s_{5.000}], [0.650, 0.800], [0.133, 0.183] \rangle$	$\langle [s_{2.833}, s_{3.833}], [0.583, 0.717], [0.150, 0.217] \rangle$	$\langle [s_{4.500}, s_{5.333}], [0.650, 0.767], [0.150, 0.200] \rangle$	$\langle [s_{3.500}, s_{4.500}], [0.667, 0.767], [0.117, 0.217] \rangle$	$\langle [s_{4.333}, s_{5.000}], [0.583, 0.733], [0.100, 0.217] \rangle$
	G^3	$\langle [s_{3.250}, s_{4.250}], [0.600, 0.825], [0.100, 0.150] \rangle$	$\langle [s_{4.000}, s_{5.000}], [0.600, 0.825], [0.125, 0.175] \rangle$	$\langle [s_{2.750}, s_{3.750}], [0.725, 0.800], [0.050, 0.175] \rangle$	$\langle [s_{3.250}, s_{3.750}], [0.600, 0.725], [0.125, 0.225] \rangle$	$\langle [s_{2.000}, s_{3.000}], [0.625, 0.800], [0.050, 0.125] \rangle$
	G^4	$\langle [s_{2.667}, s_{3.667}], [0.500, 0.633], [0.233, 0.333] \rangle$	$\langle [s_{2.333}, s_{3.333}], [0.633, 0.833], [0.033, 0.133] \rangle$	$\langle [s_{3.000}, s_{3.667}], [0.567, 0.667], [0.167, 0.267] \rangle$	$\langle [s_{3.000}, s_{3.333}], [0.600, 0.667], [0.167, 0.200] \rangle$	$\langle [s_{2.333}, s_{3.333}], [0.533, 0.800], [0.133, 0.200] \rangle$
	G^5	$\langle [s_{4.333}, s_{5.333}], [0.633, 0.767], [0.100, 0.167] \rangle$	$\langle [s_{4.667}, s_{5.333}], [0.600, 0.733], [0.033, 0.200] \rangle$	$\langle [s_{3.667}, s_{4.667}], [0.633, 0.800], [0.133, 0.167] \rangle$	$\langle [s_{3.000}, s_{4.000}], [0.533, 0.667], [0.200, 0.300] \rangle$	$\langle [s_{4.000}, s_{4.333}], [0.567, 0.767], [0.167, 0.233] \rangle$

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TABLE 7

NORMALIZED EVALUATION VALUES BY THE FIVE CLUSTERS

Suppliers	Clusters	Criteria				
		C_1	C_2	C_3	C_4	C_5
A_1	G^1	$\langle [s_{0.887}, s_{0.961}], [0.671, 0.829], [0.086, 0.157] \rangle$	$\langle [s_{0.214}, s_{0.357}], [0.114, 0.186], [0.586, 0.729] \rangle$	$\langle [s_{0.872}, s_{1.000}], [0.714, 0.843], [0.071, 0.129] \rangle$	$\langle [s_{0.667}, s_{0.786}], [0.600, 0.757], [0.071, 0.200] \rangle$	$\langle [s_{0.667}, s_{0.786}], [0.629, 0.757], [0.114, 0.200] \rangle$
	G^2	$\langle [s_{0.603}, s_{0.747}], [0.550, 0.700], [0.150, 0.233] \rangle$	$\langle [s_{0.278}, s_{0.361}], [0.083, 0.183], [0.633, 0.767] \rangle$	$\langle [s_{0.688}, s_{0.867}], [0.567, 0.783], [0.133, 0.183] \rangle$	$\langle [s_{0.583}, s_{0.694}], [0.583, 0.733], [0.050, 0.200] \rangle$	$\langle [s_{0.694}, s_{0.861}], [0.650, 0.783], [0.100, 0.167] \rangle$
	G^3	$\langle [s_{0.862}, s_{0.991}], [0.650, 0.800], [0.100, 0.150] \rangle$	$\langle [s_{0.083}, s_{0.208}], [0.075, 0.175], [0.650, 0.800] \rangle$	$\langle [s_{0.673}, s_{0.852}], [0.600, 0.750], [0.125, 0.250] \rangle$	$\langle [s_{0.625}, s_{0.750}], [0.675, 0.775], [0.100, 0.150] \rangle$	$\langle [s_{0.625}, s_{0.750}], [0.575, 0.725], [0.125, 0.225] \rangle$
	G^4	$\langle [s_{0.689}, s_{0.747}], [0.567, 0.767], [0.100, 0.233] \rangle$	$\langle [s_{0.222}, s_{0.333}], [0.100, 0.200], [0.600, 0.733] \rangle$	$\langle [s_{0.838}, s_{0.957}], [0.767, 0.867], [0.067, 0.133] \rangle$	$\langle [s_{0.889}, s_{1.000}], [0.667, 0.767], [0.067, 0.167] \rangle$	$\langle [s_{0.667}, s_{0.667}], [0.567, 0.700], [0.100, 0.200] \rangle$
	G^5	$\langle [s_{0.689}, s_{0.862}], [0.650, 0.700], [0.100, 0.250] \rangle$	$\langle [s_{0.000}, s_{0.167}], [0.050, 0.150], [0.700, 0.800] \rangle$	$\langle [s_{0.897}, s_{0.987}], [0.650, 0.800], [0.050, 0.150] \rangle$	$\langle [s_{0.583}, s_{0.667}], [0.650, 0.700], [0.050, 0.200] \rangle$	$\langle [s_{0.500}, s_{0.667}], [0.600, 0.750], [0.100, 0.150] \rangle$
A_2	G^1	$\langle [s_{0.819}, s_{0.948}], [0.663, 0.788], [0.125, 0.175] \rangle$	$\langle [s_{0.250}, s_{0.354}], [0.100, 0.212], [0.575, 0.713] \rangle$	$\langle [s_{0.740}, s_{0.897}], [0.688, 0.800], [0.088, 0.150] \rangle$	$\langle [s_{0.583}, s_{0.688}], [0.575, 0.725], [0.088, 0.200] \rangle$	$\langle [s_{0.667}, s_{0.813}], [0.663, 0.750], [0.125, 0.225] \rangle$
	G^2	$\langle [s_{0.862}, s_{1.000}], [0.580, 0.780], [0.120, 0.200] \rangle$	$\langle [s_{0.000}, s_{0.1333}], [0.080, 0.140], [0.700, 0.840] \rangle$	$\langle [s_{0.897}, s_{0.969}], [0.640, 0.780], [0.100, 0.180] \rangle$	$\langle [s_{0.633}, s_{0.767}], [0.560, 0.700], [0.140, 0.280] \rangle$	$\langle [s_{0.800}, s_{0.967}], [0.600, 0.780], [0.080, 0.200] \rangle$
	G^3	$\langle [s_{0.655}, s_{0.828}], [0.600, 0.760], [0.120, 0.220] \rangle$	$\langle [s_{0.367}, s_{0.433}], [0.120, 0.200], [0.620, 0.760] \rangle$	$\langle [s_{0.574}, s_{0.718}], [0.680, 0.780], [0.140, 0.180] \rangle$	$\langle [s_{0.367}, s_{0.467}], [0.660, 0.760], [0.080, 0.180] \rangle$	$\langle [s_{0.467}, s_{0.633}], [0.660, 0.780], [0.100, 0.200] \rangle$
	G^4	$\langle [s_{0.805}, s_{0.919}], [0.733, 0.800], [0.067, 0.200] \rangle$	$\langle [s_{0.389}, s_{0.556}], [0.067, 0.167], [0.667, 0.800] \rangle$	$\langle [s_{0.538}, s_{0.718}], [0.600, 0.733], [0.100, 0.200] \rangle$	$\langle [s_{0.667}, s_{0.778}], [0.667, 0.833], [0.100, 0.100] \rangle$	$\langle [s_{0.500}, s_{0.611}], [0.600, 0.733], [0.100, 0.267] \rangle$
	G^5	$\langle [s_{0.517}, s_{0.689}], [0.500, 0.700], [0.100, 0.100] \rangle$	$\langle [s_{0.333}, s_{0.500}], [0.100, 0.100], [0.600, 0.900] \rangle$	$\langle [s_{0.718}, s_{0.897}], [0.800, 0.900], [0.000, 0.100] \rangle$	$\langle [s_{0.833}, s_{0.833}], [0.800, 0.900], [0.100, 0.100] \rangle$	$\langle [s_{0.833}, s_{1.000}], [0.800, 0.800], [0.100, 0.200] \rangle$
A_3	G^1	$\langle [s_{0.718}, s_{0.862}], [0.617, 0.700], [0.150, 0.267] \rangle$	$\langle [s_{0.306}, s_{0.388}], [0.117, 0.200], [0.633, 0.717] \rangle$	$\langle [s_{0.778}, s_{0.957}], [0.650, 0.767], [0.083, 0.183] \rangle$	$\langle [s_{0.694}, s_{0.833}], [0.633, 0.800], [0.083, 0.183] \rangle$	$\langle [s_{0.528}, s_{0.694}], [0.600, 0.667], [0.133, 0.283] \rangle$
	G^2	$\langle [s_{0.689}, s_{0.805}], [0.667, 0.783], [0.083, 0.150] \rangle$	$\langle [s_{0.222}, s_{0.388}], [0.117, 0.267], [0.550, 0.717] \rangle$	$\langle [s_{0.598}, s_{0.688}], [0.600, 0.750], [0.100, 0.200] \rangle$	$\langle [s_{0.556}, s_{0.667}], [0.600, 0.733], [0.167, 0.267] \rangle$	$\langle [s_{0.722}, s_{0.889}], [0.650, 0.800], [0.067, 0.167] \rangle$
	G^3	$\langle [s_{0.647}, s_{0.732}], [0.675, 0.750], [0.100, 0.175] \rangle$	$\langle [s_{0.250}, s_{0.375}], [0.075, 0.150], [0.625, 0.800] \rangle$	$\langle [s_{0.493}, s_{0.583}], [0.625, 0.750], [0.100, 0.200] \rangle$	$\langle [s_{0.458}, s_{0.625}], [0.650, 0.775], [0.100, 0.200] \rangle$	$\langle [s_{0.375}, s_{0.542}], [0.625, 0.775], [0.075, 0.200] \rangle$
	G^4	$\langle [s_{0.724}, s_{0.896}], [0.660, 0.760], [0.120, 0.220] \rangle$	$\langle [s_{0.033}, s_{0.100}], [0.060, 0.140], [0.700, 0.800] \rangle$	$\langle [s_{0.754}, s_{0.933}], [0.640, 0.760], [0.100, 0.220] \rangle$	$\langle [s_{0.733}, s_{0.900}], [0.600, 0.760], [0.100, 0.180] \rangle$	$\langle [s_{0.667}, s_{0.800}], [0.600, 0.760], [0.120, 0.240] \rangle$
	G^5	$\langle [s_{0.345}, s_{0.517}], [0.500, 0.600], [0.200, 0.300] \rangle$	$\langle [s_{0.500}, s_{0.500}], [0.000, 0.100], [0.700, 0.900] \rangle$	$\langle [s_{0.359}, s_{0.359}], [0.600, 0.700], [0.100, 0.300] \rangle$	$\langle [s_{0.333}, s_{0.500}], [0.500, 0.800], [0.100, 0.200] \rangle$	$\langle [s_{0.167}, s_{0.333}], [0.700, 0.700], [0.100, 0.300] \rangle$
A_4	G^1	$\langle [s_{0.747}, s_{0.919}], [0.567, 0.700], [0.133, 0.267] \rangle$	$\langle [s_{0.250}, s_{0.306}], [0.100, 0.267], [0.533, 0.633] \rangle$	$\langle [s_{0.568}, s_{0.748}], [0.583, 0.700], [0.133, 0.217] \rangle$	$\langle [s_{0.694}, s_{0.806}], [0.617, 0.767], [0.083, 0.200] \rangle$	$\langle [s_{0.472}, s_{0.639}], [0.633, 0.700], [0.150, 0.267] \rangle$
	G^2	$\langle [s_{0.747}, s_{0.862}], [0.650, 0.800], [0.133, 0.183] \rangle$	$\langle [s_{0.361}, s_{0.528}], [0.150, 0.217], [0.583, 0.717] \rangle$	$\langle [s_{0.808}, s_{0.957}], [0.650, 0.767], [0.150, 0.200] \rangle$	$\langle [s_{0.583}, s_{0.750}], [0.667, 0.767], [0.117, 0.217] \rangle$	$\langle [s_{0.722}, s_{0.833}], [0.583, 0.733], [0.100, 0.217] \rangle$
	G^3	$\langle [s_{0.560}, s_{0.733}], [0.600, 0.825], [0.100, 0.150] \rangle$	$\langle [s_{0.167}, s_{0.333}], [0.125, 0.175], [0.600, 0.825] \rangle$	$\langle [s_{0.494}, s_{0.673}], [0.725, 0.800], [0.050, 0.175] \rangle$	$\langle [s_{0.542}, s_{0.625}], [0.600, 0.725], [0.125, 0.225] \rangle$	$\langle [s_{0.333}, s_{0.500}], [0.625, 0.800], [0.050, 0.125] \rangle$
	G^4	$\langle [s_{0.459}, s_{0.632}], [0.500, 0.633], [0.233, 0.333] \rangle$	$\langle [s_{0.444}, s_{0.611}], [0.033, 0.133], [0.633, 0.833] \rangle$	$\langle [s_{0.538}, s_{0.658}], [0.567, 0.667], [0.167, 0.267] \rangle$	$\langle [s_{0.500}, s_{0.556}], [0.600, 0.667], [0.167, 0.200] \rangle$	$\langle [s_{0.389}, s_{0.556}], [0.533, 0.800], [0.133, 0.200] \rangle$
	G^5	$\langle [s_{0.747}, s_{0.919}], [0.633, 0.767], [0.100, 0.167] \rangle$	$\langle [s_{0.111}, s_{0.222}], [0.033, 0.200], [0.600, 0.733] \rangle$	$\langle [s_{0.658}, s_{0.838}], [0.633, 0.800], [0.133, 0.167] \rangle$	$\langle [s_{0.500}, s_{0.667}], [0.533, 0.667], [0.200, 0.300] \rangle$	$\langle [s_{0.667}, s_{0.722}], [0.567, 0.767], [0.167, 0.233] \rangle$

TABLE 8

THE NORMALIZED COLLECTIVE EVALUATION MATRIX

Suppliers	C_1	C_2
A_1	$\langle[s_{0.971},s_{0.903}],[0.639,0.783],[0.098,0.185]\rangle$	$\langle[s_{0.196},s_{0.316}],[0.092,0.183],[0.619,0.756]\rangle$
A_2	$\langle[s_{0.795},s_{0.932}],[0.639,0.781],[0.105,0.191]\rangle$	$\langle[s_{0.324},s_{0.439}],[0.099,0.179],[0.621,0.779]\rangle$
A_3	$\langle[s_{0.682},s_{0.817}],[0.649,0.747],[0.113,0.201]\rangle$	$\langle[s_{0.256},s_{0.350}],[0.222,0.330],[0.446,0.637]\rangle$
A_4	$\langle[s_{0.682},s_{0.839}],[0.606,0.761],[0.128,0.202]\rangle$	$\langle[s_{0.303},s_{0.442}],[0.091,0.196],[0.591,0.741]\rangle$
Suppliers	C_3	C_4
A_1	$\langle[s_{0.824},s_{0.954}],[0.694,0.829],[0.075,0.145]\rangle$	$\langle[s_{0.711},s_{0.824}],[0.639,0.756],[0.068,0.179]\rangle$
A_2	$\langle[s_{0.761},s_{0.891}],[1.000,1.000],[0.000,0.000]\rangle$	$\langle[s_{0.702},s_{0.779}],[0.693,0.826],[0.112,0.149]\rangle$
A_3	$\langle[s_{0.660},s_{0.794}],[0.630,0.756],[0.095,0.204]\rangle$	$\langle[s_{0.614},s_{0.761}],[0.615,0.771],[0.107,0.208]\rangle$
A_4	$\langle[s_{0.644},s_{0.807}],[0.635,0.759],[0.124,0.197]\rangle$	$\langle[s_{0.583},s_{0.705}],[0.616,0.735],[0.122,0.221]\rangle$
Suppliers	C_5	
A_1	$\langle[s_{0.653},s_{0.776}],[0.616,0.753],[0.108,0.187]\rangle$	
A_2	$\langle[s_{0.723},s_{0.882}],[0.707,0.779],[0.174,0.285]\rangle$	
A_3	$\langle[s_{0.575},s_{0.732}],[0.624,0.754],[0.095,0.221]\rangle$	
A_4	$\langle[s_{0.571},s_{0.692}],[0.576,0.758],[0.134,0.225]\rangle$	

B. COMPARISONS AND DISCUSSION

To reveal the effectiveness of the developed hybrid MCDM model for green supplier selection, a comparative study is carried out in this subsection. Based on the same case example, the following green supplier selection approaches are selected for the comparison analysis: the fuzzy TOPSIS [55], the intuitionistic fuzzy GRA (IF-GRA) [56], and the interval 2-tuple linguistic VIKOR (ITL-VIKOR) [24]. Table 9 displays the results of the four timber suppliers according to the listed methods.

TABLE 9

RANKING RESULTS OF DIFFERENT METHODS

Suppliers	Fuzzy TOPSIS	IF-GRA	ITL-VIKOR	Proposed Method
A_1	2	2	2	2
A_2	1	1	1	1
A_3	3	4	4	3
A_4	4	3	3	4

From Table 9, it can be observed that the top two green suppliers derived by the three comparative models and the presented method are exactly the same. Therefore, it validates the green supplier selection framework designed in this study. Besides, the ranking derived by the proposed approach is consist with the one by the fuzzy TOPSIS method. The fuzzy TOPSIS method adopted trapezoidal fuzzy numbers to evaluate the performance of suppliers. However, it is difficult to give approximate ratings to match the linguistic phrases in the primary expression domain. Moreover, the relative importance of the distances between each alternative to the positive ideal solution and the negative ideal solution is not considered in the TOPSIS method.

In addition, there are some differences for the rankings obtained by the IFS-GRA, the ITL-VIKOR and the proposed method. According to the proposed method, A_3 ranks before A_4 while the IF-GRA and the ITL-VIKOR methods give opposite ranking. The reasons for the inconsistence may lie in the weakness of the two methods. For the IF-GRA method, IFSs are denoted as crisp values. In practice, it is difficult to determine the membership and non-membership degrees precisely. In addition, the GRA method does not take the grey relation coefficient of alternatives to the negative ideal solution into account. For the ITL-VIKOR method, the VIKOR method does not consider the relative importance of the strategy of maximum group utility and the individual regret.

Based on the above comparison analysis, it can be seen that the ranking result derived by the proposed model is more precise and credible. Comparing with the listed methods, the green supplier selection model proposed in this research has the distinctive advantages as follows:

1) A large group of decision makers are involved to cope with the green supplier selection problem, which is more practical in the real-life situation. By utilizing the ant colony algorithm, large number of decision makers can be clustered into several subgroups rapidly and effectively.
2) By applying IVIULSs, the uncertainty and vagueness of decision makers' evaluations can be captured in the proposed model. This makes decision makers to express their opinions more flexibly and the assessment procedure easier to be performed.
3) The proposed method extends the LINMAP method for determining the objective weights of evaluation criteria. It is useful to deal with conflicting preference relations between alternatives given by decision makers.
4) The modified MULTIMOORA method under IVIUL environment determines the ranking results based on three perspectives (i.e., the ratio system, the reference

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point method and the full multiplicative form). Thus, a more precise and reliable ranking of green suppliers can be acquired according to this method.

VI. CONCLUSIONS

In this study, we developed a hybrid MCDM model to address the green supplier selection problem involving large group of decision makers. As a new representation of uncertain linguistic information, IVIULSs were utilized for dealing with decision makers' diversity assessments of suppliers. Ant colony algorithm is utilized to cluster the large number of decision makers into subgroups. An extension of the classical LINMAP method is used for computing the optimal weights of evaluation criteria. Finally, a modified MULTIMOORA approach is applied to rank the alternative green suppliers. A real-life example of a real estate company is implemented to reveal the efficiency of the proposed large group green supplier selection approach. The results show that the proposed approach can better reflect the hesitation and fuzziness of experts' evaluations and obtain a more accurate ranking order of the candidate suppliers.

In this work, the evaluation criteria are supposed to be independent in the green supplier selection. Future research should be conducted to address the inter-dependence among evaluation criteria in GSCM. Besides, it is prospective to apply heterogeneous information for evaluating green suppliers since suppliers' performance on different criteria may be expressed in different forms. Finally, the developed model can be used to handle other large group decision making problems, including robot selection, human resource management and factory location.

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