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Yours sincerely,

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Evaluating green supplier development programs by a new decision interval-valued fuzzy model-based possibilistic statistical concept

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Abstract—Enhancing environmental performance of suppliers is important for green supply chains. Numerous companies have assigned resources to different green supplier development programs to improve their supplier performances. The decision to select the appropriate program for green supplier improvement is a challenging decision because of prior experience, limited quantitative information, and different supplier backgrounds. In this paper, a new decision interval-valued fuzzy model based on possibilistic statistical concepts is provided for appraising development programs of green suppliers. Two new versions of technique for order preference by similarity to ideal solution (TOPSIS) and Entropy method are introduced to solve the development programs evaluation problem. Then, an application example in the manufacturing industry is presented and solved by proposed decision interval-valued fuzzy model under uncertainty.

Keywords—Green supplier development program; interval-valued fuzzy sets; TOPSIS method; entropy method.

I. Introduction

Green supply chain management has observed significant advancement in the last two decades (Seuring and Muller, 2008). It is the combination of common ecological worries into supply chain management. There are numerous exercises and elements that might be taken within this organizational practice, for instance, incorporate selecting green suppliers and incorporating fusing supplier contribution to greening authoritative practices [1-4].

Regarding the evaluation of green supplier development programs, Chiou et al. [5] considered analytic hierarchy process (AHP) and provided fuzzy AHP for appraising green suppliers using six factors with 24 sub-factors. The case could decide the relative significance of appraising green suppliers over a multicultural setting. Yan [6] presented a combined methodology receiving a genetic algorithm and AHP to obtain and optimized appraisement of green suppliers. Buyukozkan and Cifci [7, 8] focused on a methodology with a fuzzy feedback approach with preference relationships under uncertainty. Fu et al. [9] presented an organized administrative methodology for companies to assess the impact connections amongst development programs of green suppliers by grey modeling. Blome et al. [10] regarded the contradicting hypothetical perspectives of authenticity in assessing firm performance along with administration responsibility. Akman [11] assessed suppliers to include green supplier development programs via fuzzy c-means and compromise ranking (VlseKriterijumska Optimizacija I Kompromisno Resenje, namely VIKOR) techniques. Awasthi and Kannan [12] developed and considered the issue of assessing green supplier advancement programs by a fuzzy NGT and VIKOR-based approach.

The above-related literature on the green supplier development programs denotes that an assessment of selection problem is a multi-criteria group decision-making (MCGDM) framework for the supply chain management (SCM), and is regarded as a new research area. In practice, several evaluation factors or criteria can influence this selection issue under uncertain conditions.

In this paper, an evaluation approach for development programs of green supplier is presented with a new decision-making model by interval-valued fuzzy sets and possibilistic statistical concepts. For this purpose, two new versions of technique for order preference by similarity to ideal solution (TOPSIS) and Entropy methods are introduced to solve the development programs evaluation problem. Two possibilistic mean and possibilistic standard deviation matrices are presented. Then, an application example in the manufacturing industry is presented and solved by proposed decision interval-valued fuzzy model under uncertainty.

The rest of the paper is organized as follows. Section 2 presents the research background followed by the proposed approach in Section 3. Section 4 contains the illustrative example. Finally, conclusions are given in Section 5.

II. Preliminaries

A. Interval-Valued Fuzzy Sets

The interval-valued fuzzy numbers have been considered as a special form of generalized fuzzy numbers. These fuzzy numbers can contain interval-valued trapezoidal fuzzy numbers, triangular shape, and interval-valued triangular fuzzy numbers. A graphical representation of an interval-valued triangular fuzzy number is depicted in Fig. 1. According to Yao and Lin [13], an interval-valued triangular fuzzy number is represented as follows:

$$\tilde{A} = \left[\underset{\sim}{\tilde{A}}, \tilde{\tilde{A}}\right] = \left[\left(\underline{a}_1, \underline{a}_2, \underline{a}_3; \hat{\underline{h}}_{\tilde{A}}\right), \left(\overline{a}_1, \overline{a}_2, \overline{a}_3; \hat{\hat{h}}_{\tilde{A}}\right)\right] \tag{1}$$

Suppose $\underline{\tilde{A}}$ and $\tilde{\tilde{A}}$ be two generalized triangular fuzzy numbers (GTFN) as depicted in Fig. 2; hence, $\hat{\underline{h}}_{\tilde{A}}$ and $\hat{\hat{h}}_{\tilde{A}}$ define the heights of $\underline{\tilde{A}}$ and $\tilde{\tilde{A}}$, and $\underline{a}_1, \underline{a}_2, \underline{a}_3$, $\overline{a}_1, \overline{a}_2, \overline{a}_3$ define the real values. $GTFN\ \tilde{A}$ denoted in the universe of discourse X is described by: $0 \le \underline{a}_1 \le \underline{a}_2 \le \underline{a}_3 \le 1$, $0 \le \overline{a}_1 \le \overline{a}_2 \le \overline{a}_3 \le 1$, $\overline{a}_1 \le \underline{a}_1$ and $\underline{a}_3 \le \overline{a}_3$. In addition, $\underline{\tilde{A}} = \left(\underline{a}_1, \underline{a}_2, \underline{a}_3; \hat{\underline{h}}_{\tilde{A}}\right)$, $\tilde{\tilde{A}} = \left(\overline{a}_1, \overline{a}_2, \overline{a}_3; \hat{\hat{h}}_{\tilde{A}}\right)$ and $\underline{\tilde{A}} \subset \tilde{\tilde{A}}$ are regarded.

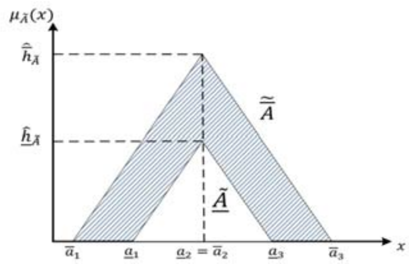

Fig. 1. Interval-Valued Fuzzy Number

B. Possibility Theory

A fuzzy number $\tilde{A}$ will be a fuzzy arrangement of the real line x with a normal, fuzzy convex and continuous membership function of limited support [14-16]. Let $\tilde{A} \in x$ be fuzzy number with $[\tilde{A}]^{\gamma} = [a_1(\gamma), a_2(\gamma)], \gamma \in [0,1]$. The possibilistic mean estimations of fuzzy number $\tilde{A}$ is denoted as $M(\tilde{A}) = \int_0^1 \gamma\left(a_1(\gamma) + a_2(\gamma)\right)$, and the possibilistic difference of $\tilde{A}$ as $Var(\tilde{A}) = \frac{1}{2}\int_0^1 \gamma(a_1(\gamma) - a_2(\gamma))^2 d\gamma$.

Let $\tilde{A}$ be a triangular fuzzy number with focus a, left-width $\tau > 0$, right-width $\sigma > 0$, i.e. $\tilde{A} = (a - \tau, a, a + \sigma)$. $A\ \gamma$-level arrangement of fuzzy number $\tilde{A}$ can be calculated by:

$$[\tilde{A}]^{\gamma} = [a - (1 - \gamma)\tau, a + (1 - \gamma)\sigma], \forall\gamma \in [0,1] \tag{2}$$

Based on above-mentioned explanations, the possibilistic mean estimation of triangular fuzzy number $\tilde{\xi} = (a, b, c)$ is presented by:

$$\begin{aligned} M(\tilde{\xi}) = e = \int_0^1 \gamma\big((a - (1 - \gamma)\tau) \\ + (a + (1 - \gamma)\sigma)\big)d\gamma \\ = (a + 2b + c)/4 \end{aligned} \tag{3}$$

Possibilistic variance of triangular fuzzy number $\tilde{\xi}$ can be given as follows:

$$\begin{aligned} &Var(\tilde{\xi}) \\ &= \int_0^1 \gamma\big((a - (1 - \gamma)\tau) + (a + (1 - \gamma)\sigma)\big)^2 d\gamma \\ &= (33\alpha_1^3 + 21\alpha_1^2\gamma + 11\alpha_1\gamma^2 - \gamma^3)/384\alpha_1 \end{aligned} \tag{4}$$

where $\alpha_1 = \max\{b - a, c - b\}$ and $\gamma = \min\{b - a, c - b\}$.

III. Proposed New Evaluation Model For Green Supplier Development Programs

In this section, a new procedure based on an interval-valued fuzzy group approach for green supplier development programs is presented based on possibility theory and statistical concepts. First, it is assumed that:

$DM = \{DM^k | k = 1, \dots, p\}$ as a set of supply chain team members, $X = \{X_i | i = 1, \dots, m\}$ as a set of green supplier development programs candidates, $C = \{C_j | j = 1, \dots, n\}$ as a set of criteria for green supplier development problem.

Since the information of green supplier development programs candidates is uncertain during group decision making in SCM, the supply chain decision makers or experts can consider an interval-valued fuzzy (IVF) $\tilde{A}_{ij}^k$ to estimate the judgment and opinion on sustainable supplier candidate X_i with respect to supplier criterion C_i. The problem of green supplier development programs with interval-valued fuzzy sets and statistical concepts can be expressed in matrix form:

$$\tilde{A}^k = \left[[(\underline{a}_{ij_1}, \underline{a}_{ij_2}, \underline{a}_{ij_3}), (\overline{a}_{ij_1}, \overline{a}_{ij_2}, \overline{a}_{ij_3})]^k\right]_{m\times n} \tag{5}$$

For convenience, we denote:
$\left[\left(\underline{a}_{ij_1}, \underline{a}_{ij_2}, \underline{a}_{ij_3}\right), \left(\overline{a}_{ij_1}, \overline{a}_{ij_2}, \overline{a}_{ij_3}\right)\right]^k = [(\underline{a}_{ij} - \underline{\tau}_{ij}, \underline{a}_{ij}, \underline{a}_{ij} + \underline{\sigma}_{ij}), (\overline{a}_{ij} - \overline{\tau}_{ij}, \overline{a}_{ij}, \overline{a}_{ij} + \overline{\sigma}_{ij})]^k$ for kth TM.

According to the above-mentioned descriptions, steps of the proposed interval-valued fuzzy procedure are presented for the evaluation and selection problem of the green supplier development programs as follows:

Step 1. Proper criteria are identified for the evaluation problem of the green supplier development programs.

Step 2. Provide the IVF-decision matrices of green supplier development programs candidates, and aggregate them. The aggregated IVF-decision matrices of the green supplier development programs candidates are obtained by the arithmetic average with the following relation, respectively:

$$\begin{aligned} &\underline{a}_{ijl} = \frac{1}{p}\sum_{k=1}^{p}\left(\underline{a}_{ij_l}\right)^k \ ; l = 1,2,3 \\ &\text{and } \overline{a}_{ijl} = \frac{1}{p}\sum_{k=1}^{p}(\overline{a}_{ij_l})^k \ ; l = 1,2,3 \end{aligned} \tag{6}$$

Step 3. Transform the aggregated IVF-matrix into the normalized matrix of the green supplier development programs candidates. To transform different criteria scales into a comparable scale, the linear scale transformation method is used and presented by:

$$\tilde{a}'_{ij} = \left[\left(\underline{a}'_{ij_1}, \underline{a}'_{ij_2}, \underline{a}'_{ij_3}\right), \left(\overline{a}'_{ij_1}, \overline{a}'_{ij_2}, \overline{a}'_{ij_3}\right)\right] = \left[\left(\frac{\underline{a}_{ij} - \underline{\tau}_{ij}}{\left(\overline{a}_{ij} + \overline{\sigma}_{ij}\right)^+}, \frac{\underline{a}_{ij}}{\left(\overline{a}_{ij} + \overline{\sigma}_{ij}\right)^+}, \frac{\underline{a}_{ij} + \underline{\sigma}_{ij}}{\left(\overline{a}_{ij} + \overline{\sigma}_{ij}\right)^+}\right), \left(\frac{\overline{a}_{ij} - \overline{\tau}_{ij}}{\left(\overline{a}_{ij} + \overline{\sigma}_{ij}\right)^+}, \frac{\overline{a}_{ij}}{\left(\overline{a}_{ij} + \overline{\sigma}_{ij}\right)^+}, \frac{\overline{a}_{ij} + \overline{\sigma}_{ij}}{\left(\overline{a}_{ij} + \overline{\sigma}_{ij}\right)^+}\right)\right], j \in \Omega_b \tag{7}$$

and

$$\tilde{a}'_{ij} = \left[\left(\underline{a}'_{ij_1}, \underline{a}'_{ij_2}, \underline{a}'_{ij_3}\right), \left(\overline{a}'_{ij_1}, \overline{a}'_{ij_2}, \overline{a}'_{ij_3}\right)\right] = \left[\left(\frac{\left(\overline{a}_{ij} - \overline{\tau}_{ij}\right)^-}{\underline{a}_{ij} + \underline{\sigma}_{ij}}, \frac{\left(\overline{a}_{ij} - \overline{\tau}_{ij}\right)^-}{\underline{a}_{ij}}, \frac{\left(\overline{a}_{ij} - \overline{\tau}_{ij}\right)^-}{\underline{a}_{ij} - \underline{\tau}_{ij}}\right), \left(\frac{\left(\overline{a}_{ij} - \overline{\tau}_{ij}\right)^-}{\overline{a}_{ij} + \overline{\sigma}_{ij}}, \frac{\left(\overline{a}_{ij} - \overline{\tau}_{ij}\right)^-}{\overline{a}_{ij}}, \frac{\left(\overline{a}_{ij} - \overline{\tau}_{ij}\right)^-}{\overline{a}_{ij} - \overline{\tau}_{ij}}\right)\right], j \in \Omega_c \tag{8}$$

where Ω_b and Ω_c are the sets of benefit and cost attributes for the green supplier development programs evaluation problem, respectively.

$\left(\overline{a}_{ij} + \overline{\sigma}_{ij}\right)^+ = \max_i\left(\overline{a}_{ij} + \overline{\sigma}_{ij}\right), i = 1,..,m$, $\left(\overline{a}_{ij} - \overline{\tau}_{ij}\right)^- = \min_i\left(\overline{a}_{ij} - \overline{\tau}_{ij}\right), i = 1,..,m$, and $k = 1,\dots,p$.

The maximum rating of each green supplier development programs candidate against each criterion and the minimum rating using the normalization process can be obtained. For convenience, it is denoted as follows:

$$\left[\left(\underline{a}'_{ij_1}, \underline{a}'_{ij_2}, \underline{a}'_{ij_3}\right), \left(\overline{a}'_{ij_1}, \overline{a}'_{ij_2}, \overline{a}'_{ij_3}\right)\right]^k = \left[\left(\underline{a}'_{ij} - \underline{\tau}'_{ij}, \underline{a}'_{ij}, \underline{a}'_{ij} - \underline{\sigma}'_{ij}\right), \left(\overline{a}'_{ij} - \overline{\tau}'_{ij}, \overline{a}'_{ij}, \overline{a}'_{ij} - \overline{\sigma}'_{ij}\right)\right]^k$$

Step 4. Build possibilistic mean interval value matrix for the assessment issue of the programs alternatives. The possibilistic mean interval values ($\breve{m}_{ij}$) of IVF $\widetilde{a'}_{ij} = \left[\left(\underline{a}'_{ij} - \underline{\tau}'_{ij}, \underline{a}'_{ij}, \underline{a}'_{ij} - \underline{\sigma}'_{ij}\right), \left(\overline{a}'_{ij} - \overline{\tau}'_{ij}, \overline{a}'_{ij}, \overline{a}'_{ij} - \overline{\sigma}'_{ij}\right)\right]$ are defined according to Eq. (3):

$$\breve{m}_{ij} = \left[\underline{m}_{ij}, \overline{m}_{ij}\right] = \left[\frac{\left(\underline{a}'_{ij_1} + 2 \times \underline{a}'_{ij_2} + \underline{a}'_{ij_3}\right)}{4}, \frac{\left(\overline{a}'_{ij_1} + 2 \times \overline{a}'_{ij_2} + \overline{a}'_{ij_3}\right)}{4}\right] \tag{9}$$

Then, the possibilistic mean interval value matrix is constructed for the evaluation problem of green supplier development programs candidates as follows:

$$\breve{M} = \left[\breve{m}_{ij}\right]_{m\times n} = \begin{bmatrix} \breve{m}_{11} & \breve{m}_{12} & \cdots & \breve{m}_{3n} \\ \breve{m}_{21} & \breve{m}_{22} & \cdots & \breve{m}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \breve{m}_{m1} & \breve{m}_{m2} & \cdots & \breve{m}_{mn} \end{bmatrix} \tag{10}$$

Step 5. Construct the possibilistic standard deviation interval value matrix for the evaluation problem of green supplier development programs candidates. The interval possibilistic standard deviation ($\breve{sd}_{ij}$) of IVF $\widetilde{a'}_{ij} = \left[\left(\underline{a}'_{ij} - \underline{\tau}'_{ij}, \underline{a}'_{ij}, \underline{a}'_{ij} - \underline{\sigma}'_{ij}\right), \left(\overline{a}'_{ij} - \overline{\tau}'_{ij}, \overline{a}'_{ij}, \overline{a}'_{ij} - \overline{\sigma}'_{ij}\right)\right]$ are determined according to Eq. (4):

$$\breve{sd}_{ij} = \left[\underline{sd}_{ij}, \overline{sd}_{ij}\right] = \left[\sqrt[2]{\frac{33\left(\underline{\alpha}_{ij}\right)^3 + 21\left(\underline{\alpha}_{ij}\right)^2\left(\underline{\gamma}_{ij}\right) + 11\left(\underline{\alpha}_{ij}\right)\left(\underline{\gamma}_{ij}\right)^2 - \left(\underline{\gamma}_{ij}\right)^3}{384\left(\underline{\alpha}_{ij}\right)}}, \sqrt[2]{\frac{33\left(\overline{\alpha}_{ij}\right)^3 + 21\left(\overline{\alpha}_{ij}\right)^2\left(\overline{\gamma}_{ij}\right) + 11\left(\overline{\alpha}_{ij}\right)\left(\overline{\gamma}_{ij}\right)^2 - \left(\overline{\gamma}_{ij}\right)^3}{384\left(\overline{\alpha}_{ij}\right)}}\right] \tag{11}$$

where $\underline{\alpha} = \max\{\underline{\tau}'_{ij}, \underline{\sigma}'_{ij}\}$ and $\underline{\gamma} = \min\{\underline{\tau}'_{ij}, \underline{\sigma}'_{ij}\}$ and $\overline{\alpha} = \max\{\overline{\tau}'_{ij}, \overline{\sigma}'_{ij}\}$ and $\overline{\gamma} = \min\{\overline{\tau}'_{ij}, \overline{\sigma}'_{ij}\}$.

Then, the possibilistic standard deviation interval value matrix is constructed for the evaluation problem of green supplier development programs candidates as follows:

$$\breve{SD} = \left[\breve{sd}_{ij}\right]_{m\times n} = \begin{bmatrix} \breve{sd}_{11} & \breve{sd}_{12} & \cdots & \breve{sd}_{3n} \\ \breve{sd}_{21} & \breve{sd}_{22} & \cdots & \breve{sd}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \breve{sd}_{m1} & \breve{sd}_{m2} & \cdots & \breve{sd}_{mn} \end{bmatrix} \tag{12}$$

Step 6. Compute entropy weighting method based on mean-variance concepts.

Sub-steps 6.1. Calculate possibilistic mean entropy measure with interval values for each green supplier development evaluation criterion.

$$\breve{E}(m)_j = \left[\underline{e}(m)_j, \overline{e}(m)_j\right] = \left[-\frac{1}{Ln(m)}\sum_{i=1}^{m} \overline{m}'_{ij} Ln\left(\overline{m}'_{ij}\right), -\frac{1}{Ln(m)}\sum_{i=1}^{m} \underline{m}'_{ij} Ln\left(\underline{m}'_{ij}\right)\right] \tag{13}$$

where $\overline{m}'_{ij} = \left[\underline{m}'_{ij}, \overline{m}'_{ij}\right] = \left[\frac{\underline{m}_{ij}}{\max_i \overline{m}_{ij}}, \frac{\overline{m}_{ij}}{\max_i \overline{m}_{ij}}\right]$.

Sub-steps 6.2. Calculate possibilistic standard deviation entropy measure with interval values for each green supplier development evaluation criterion.

$$\breve{E}(sd)_j = [\underline{e}(sd)_j, \overline{e}(sd)_j] = \left[-\frac{1}{Ln(m)}\sum_{i=1}^{m}\overline{sd'}_{ij}Ln(\overline{sd'}_{ij}),\ -\frac{1}{Ln(m)}\sum_{i=1}^{m}\underline{sd'}_{ij}\mathrm{Ln}(\underline{sd'}_{ij})\right] \quad (14)$$

where $\widetilde{sd}'_{ij} = [\underline{sd'}_{ij}, \overline{sd'}_{ij}] = \left[\frac{\underline{sd}_{ij}}{max_i \overline{sd}_{ij}}, \frac{\overline{sd}_{ij}}{max_i \overline{sd}_{ij}}\right]$.

Step 7. Calculate final weights of green supplier development evaluation criteria based on mean-variance concepts.

Sub-step 7.1. Calculate proposed entropy weight based on the possibilistic mean interval values.

$$\breve{W}(m)_j = [\underline{w}(m)_j, \overline{w}(m)_j] = [1 - \overline{e}(m)_j, 1 - \underline{e}(m)_j] \quad (15)$$

Sub-step 7.2. Calculate proposed entropy weight based on the possibilistic standard deviation interval values.

$$\breve{W}(sd)_j = [\underline{w}(sd)_j, \overline{w}(sd)_j] = [1 - \overline{e}(sd)_j, 1 - \underline{e}(sd)_j] \quad (16)$$

Step 8. Define positive-ideal (PIV) of possibilistic mean interval values for the evaluation problem of green supplier development programs candidates. The PIV ($\breve{M}^*$) are calculated by:

$$\breve{M}^* = \{\breve{M}_1^*, \breve{M}_2^*, \dots, \breve{M}_n^*\} = \{[\underline{m}_j^*, \overline{m}_j^*]\} = \left\{\max_i \breve{m}_{ij} \,\middle|\, i = 1,2,\dots,m\right\} \quad (17)$$

Step 9. Define positive-ideal and negative-ideal vector (PIV and NIV) of possibilistic standard deviation of interval values. The PIV ($\widetilde{SD}^*$) are determined by:

$$\widetilde{SD}^* = \{\widetilde{SD}_1^*, \widetilde{SD}_2^*, \dots, \widetilde{SD}_n^*\} = \left\{\left[\underline{sd}_j^*, \overline{sd}_j^*\right]\right\} = \left\{\min_i \widetilde{sd}_{ij} \,\middle|\, i = 1,2,\dots,m\right\} \quad (18)$$

Step 10. Calculate the separation measures matrix according to mean and standard deviation of interval-number from the PIV ($\breve{M}^*$, $\widetilde{SD}^*$), respectively.

The separation vectors of mean, standard deviation of interval value matrix from the PIV are obtained for the selection problem of sustainable suppliers as below:

$$\Gamma_i = m_{D_{ij}^*}(\breve{m}_{ij}, \breve{M}_j^*) = \sqrt{\sum_{j=1}^{n}\left(\underline{w}(m)_j(\underline{m}_j^* - \underline{m}_{ij})^2 + \overline{w}(m)_j(\overline{m}_j^* - \overline{m}_{ij})^2\right)} \quad (19)$$

$$K_i = sd_{\mathrm{D}_{ij}^*}(\widetilde{sd}_{ij}, \widetilde{SD}_j^*) = \sqrt{\sum_{j=1}^{n}\left(\underline{w}(sd)_j(\underline{sd}_j^* - \underline{sd}_{ij})^2 + \overline{w}(sd)_j(\overline{sd}_j^* - \overline{sd}_{ij})^2\right)} \quad (20)$$

Step 11. The final score is calculated using a linear combination closeness coefficient of alternative X_i.

$$Sc_i = \alpha\Gamma_i + \beta K_i \quad (21)$$

where $\sum \alpha + \beta = 1$, $0 \le \alpha \le 1$, $0 \le \beta \le 1$.

Step 12. Rank the preference order of all alternatives as per the incorporated relative closeness coefficient, and select the best one.

IV. Illustrative Example

An automobile manufacturing company is considered from the recent study in the literature [12]. To accomplish the objective, the organization is advancing the utilization of environment friendly practices in all procedures of the association, green provider advancement being one of them. To make best utilization of time and assets, the organization considered on surveying three green supplier improvement programs, including mandatory ISO 14000 certification (*P*$_1$), supplier training (*P*$_2$), and employee deployment with environment expertise at supplier locations (*P*$_3$) for the implementation a board of three expert specialists (DM_1, DM_2, and DM_3) toward surveying and regarding the best green supplier development program(s) for usage.

The committee applies the criteria for green supplier development program assessment as below: Time (C_1), Cost (C_2), Labor (C_3), Resources (C_4), Energy usage (C_5), Water (C_6), Emissions (C_7), Noise (C_8), Waste (C_9), Green packaging (C_{10}), Green manufacturing (C_{11}), Green product design (C_{12}), Green transportation (C_{13}), Green warehousing (C_{14}), Green procurement (C_{15}), and Reverse logistics (C_{16}).

Linguistic ratings regarding to the appraisement criteria and the development programs of green suppliers as candidates are given using Tables I & II.

TABLE I. Linguistic variables

Linguistic variables	Interval-valued fuzzy numbers
Very Poor (VP)	[(0.00,0.00,2.00), (0.00,0.00,3.50)]
Poor (P)	[(1.00,2.50,4.00), (0.00,2.50,6.00)]
Fair (F)	[(3.50,5.00,6.50), (2.00,5.00,8.00)]
Good (G)	[(6.00,7.50,9.00), (4.00,7.50,10.00)]
Very Good (VG)	[(8.00,10.00,10.00), (6.50,10.00,10.00)]

Following are the final weights of green supplier development evaluation criteria based on mean-variance concepts calculated for the evaluation problem of the green supplier development programs candidates. Table III shows the computational results of the proposed new evaluation model.

$\breve{W}(m)_j = [\underline{w}(m)_j, \overline{w}(m)_j] =$
[(0.55,0.58), (0.65,0.71), (0.64,0.69), (0.48,0.52), (0.46,0.49), (0.66,0.68), (0.54,0.58), (0.47,0.48), (0.46,0.49), (0.70,0.73), (0.62,0.66), (0.68,0.62), (0.60,0.64), (0.33,0.33), (0.72,0.76), (0.35,0.39)].
and
$\breve{W}(m)_j = [\underline{w}(m)_j, \overline{w}(m)_j] =$
[(0.03,0.64), (0.07,0.92), (0.04,0.74), (0.07,0.85), (0.04,0.85), (0.05,0.79), (0.04,0.91), (0.05,0.77), (0.08,0.92), (0.04,0.91), (0.03,0.67), (0.06,0.76), (0.04,0.78), (0.05,0.87), (0.07,0.98), (0.03,0.86)].

TABLE II. Linguistic assessments for three alternatives

Criteria	P1			P2			P3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1	P	P	VG	VP	VG	VP	G	G	P
C2	VP	P	VP	VP	VP	F	G	P	VP
C3	G	VG	VP	VG	VG	F	VG	G	VP
C4	P	VP	VG	VP	VP	F	G	G	VP
C5	F	G	P	G	F	F	P	VG	P
C6	VG	P	VG	F	F	F	P	F	P
C7	VP	F	F	G	P	G	F	F	F
C8	F	VG	VG	F	F	VP	F	VP	P
C9	VP	G	G	G	VP	VP	F	VG	P
C10	G	F	F	G	P	VG	G	F	P
C11	G	VP	VG	VG	G	P	P	VG	VP
C12	VP	F	VG	VP	VP	VP	G	VP	F
C13	P	G	F	VG	VG	F	P	VG	VG
C14	VP	P	P	VP	VP	F	F	VG	F
C15	VG	P	G	VP	G	F	P	G	VG
C16	G	G	G	P	F	F	F	VP	F

TABLE III. Computational results of the model

Green supplier development programs	$\Gamma_i = m_{D_{ij}^*}(\widetilde{m}_{ij}, \widetilde{M}_j^*)$	$K_i = sd_{D_{ij}^*}(\widetilde{sd}_{ij}, \widetilde{SD}_j^*)$	Sc_i	Ranking order
P_1	0.945061	0.067936	0.506498	2
P_2	1.071516	0.072928	0.572222	3
P_3	0.844923	0.074872	0.459898	1

The resulting outcomes of the proposed model would help managers prioritize their green supplier development programs concentrating on programs by delivering greater supplier performance. The assessment and selection can assist resource and investment allocations.

V. Conclusion

Environmental performance of an organization in the supply chain could be evaluated by the organization's own natural endeavors and the execution of its suppliers. Helpful association with suppliers respected ecological issues permits organizations to enhance their ecological execution. Organizations request their suppliers to regard the needed natural accreditations and to characterize green applications. The end goal to build up their ecological capabilities, organizations ought to make agreeable, close and coordinated associations with their suppliers, assess green execution of their suppliers, and help suppliers about green programs' issues. This paper presents a new evaluation model for green supplier development programs by integrating interval-valued fuzzy sets and possibilistic statistical concepts. For this purpose, a new decision-making process under an interval-valued fuzzy environment is introduced based on the technique for order of preference by similarity to ideal solution (TOPSIS) method, two possibilistic mean and possibilistic standard deviation. In addition, a new version of entropy method is developed for computing the weight of each evaluation criterion with possibilistic statistical concepts. New closeness coefficient of alternative indexes are also presented to provide a final order of green supplier development programs. Finally, the validity of the proposed model was illustrated by an application example in the manufacturing industry from the recent literature. The decision modelling effort is able to regard uncertainties, and users of the proposed model should understand that the uncertainties additionally available in what elements ought to be incorporated and managerial perceptions related to the factors.

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