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COPRAS METHOD FOR MULTIPLE ATTRIBUTE GROUP DECISION MAKING UNDER PICTURE FUZZY ENVIRONMENT AND THEIR APPLICATION TO GREEN SUPPLIER SELECTION

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Abstract. The green supplier selection (GSS) is a significant part in green supply chain management (GSCM). Choosing optimal green supplier can not only realize the sustainable development of enterprises, but also maximize the utilization rate of resources and diminish the negative effect of environmental issues, which conforms to the theme of green development. As a multiple attribute group decision-making (MAGDM) issue, selecting optimal green supplier is of vital important to enterprises. However, how to select the optimal supplier for enterprises is a great challenge. To handle this issue, a novel picture fuzzy COPRAS (COmplex PRoportional Assessment) method is devised. First, some necessary theories related to picture fuzzy sets (PFSs) are briefly reviewed. In addition, a method called CRITIC (Criteria Importance Though Intercriteria Correlation) is utilized to calculate criteria's weights. Afterwards, the conventional COPRAS method is extended to the PFSs to calculate each alternative's utility degree. At last, the designed method is exacted to an application which is related to GSS and there also conduct some comparative analysis to demonstrate the designed method's superiority. The final results show that the proposed model can be utilized to decide the optimum green supplier.

Keywords: multiple attribute group decision-making (MAGDM), picture fuzzy sets (PFSs), COPRAS method, CRITIC method, green supplier selection.

JEL Classification: C43, C61, D81.

Introduction

Recently, green supply chain management (GSCM) has been prospered and many scholars and managers have attached great importance to it. The definition of GSCM was initially developed by Min and Kim (2012) which was the environment-friendly management of supply chain activities from the beginning to the end. Mohanty and Prakash (2014) viewed GSCM

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as a strategy which can be utilized to enhance productivity and environmental performance for overall socio-economic development. Compared with the conventional supplier selection, Akcan and Tas (2019) pointed out that GSS not only pay attention to profitability, customer satisfaction and quality, but also focus on the ecological concerns like carbon dioxide emission, resources waste and social responsibility. In other words, GSS can balance economic and environment benefits. Thus, for enterprises, selecting the suitable green supplier can be viewed as a vital strategy and the scientific and rational selection methods and criteria are urgently needed.

However, selecting the optimal green suppliers is a great challenge for enterprises. Assessing green suppliers need to consider various elements, such as qualitative and quantitative information. What's more, in the process of GSS, enterprises often assess their supplier candidates by voting at the meeting. Nowadays, utilizing crisp numbers or other fuzzy sets to assess qualitative and quantitative information is hardly to express the experts' cognitive information, especially for the neutral and reject information. Compared with intuitionistic fuzzy sets (IFSs), picture fuzzy (PFSs) can model and represent the experts' cognitive information for better. Therefore, to help enterprises obtain accurately and comprehensively evaluation information, using PFSs is an optimal choice. Hence, a novel picture fuzzy MAGDM method which relies on the extended COPRAS method is devised to address the GSS issues. COPRAS method was initially developed by Zavadskas et al. (1994) to tackle the MAGDM issues, which was viewed as one of the simplest methods to acquire the final decision. Contrast with other MAGDM methods, this method can not only address the information from different angles, but also show the differences between each alternative and the ideal or non-ideal alternative. Our work's novelties can be summarized subsequently:

(1) An evaluation system for the GSS is presented, which can support enterprises to select the suitable suppliers in an efficient way.
(2) Though this method has been presented for decades, the number of the related researches are scarce in the existing literature. Thus, this work which constructs picture fuzzy COPRAS method can fill this research gap.
(3) In the supplier selection, there exist amount of criteria with different weights. Due to the DMs may be constrained by their knowledge and experience, it is difficult to allocate the criteria weights precisely. In this essay, an objective weight determining approach based on the CRITIC approach is presented to compute the values of weight.

This essay's reminder proceeds subsequently. In section 1, a related literature review is given. In section 2, some fundamental concepts of PFSs is concisely retrospect. In section 3, the conventional COPRAS method is combined with PFSs and the computing procedures are simply given. An example about green supplier selection is designed to illustrate this approach' merits and some comparative analysis are also provided to further prove this method' merits in section 4. At last, a comprehensive conclusion of our work is made in the last section.

1. Literature review

1.1. The evaluation criteria for green supplier selection

In the green supplier selection (GSS), building a scientific evaluation criteria system is essential. There have been various criteria in the supplier selection. But in the process of GSS, Elkington (1998) pointed out that there were the triple bottom line should be observed, including economic, environmental and society. Ho et al. (2010) summarized the most popular evaluation criteria from a variety of researches, which were quality, technology, flexibility and delivery etc. Harridan and Cheaitou (2017) found environment management system was the most common criterion which contained eco-design, green image and green performance etc. Liu et al. (2018) thought that occupational health and safety systems and information disclosure were related to this issue.

1.2. The evaluation method for green supplier selection

There has involved various criteria in the process of GSS. In an intricate environment, it is risky for an enterprise to allow a singular decision maker (DM) to select the optimal green supplier. Because the decision information that the DM collected is limited. The amount of information will affect how he know about these suppliers. What's more, the decision he made is also influenced by his expertise knowledge and industry experience. These factors may lead him to make errors when he evaluates these suppliers on the basis of multi-attributes. Hence, enterprises are increasingly inclined to organize a panel of experts to handle these kind of multi-attributes issues. Up to now, there has existed some MAGDM techniques to select green supplier, such as AHP, ANP and TOPSIS. To be specific, Kilic and Yalcin (2020) designed a technique by integrating IF-TOPSIS method with a modified two-phase fuzzy goal programming model to tackle GSS issues. Pishchulov et al. (2019) put forward a modified VAHP method to support the related managers to choose suppliers. Wang et al. (2019a) combined FAHP with TOPSIS methods to optimize the process of assessing and choosing supplier. Wu et al. (2019c) utilized BWM and VIKOR techniques under the interval type-2 fuzzy environment to handle GSS issues. Xu et al. (2019) designed the AHP-Sort-II method with IT2FSs to prompt the development of sustainable supplier selection. Fei et al. (2019) presented a MCDM method by combining ELECTRE with DST approaches to improve the precision of GSS. Kaya and Yet (2019) introduced DEMATEL method which was frequently utilized MCDM method to Bayesian Networks to establish a framework for GSS. Liao et al. (2019) extended the social participatory allocation network (SPAN) and ANP methods to hesitant fuzzy linguistic environment to developed a novel model for choosing the suitable low carbon supplier.

1.3. Review about picture fuzzy set

Owing to the increasing complicated in the process of decision-making, decision makers (DMs) frequently need to express their cognitive information for some issues with inherent uncertainty and ambiguity information. To better express DMs' preference information, Atanassov (1986) proposed the intuitionistic fuzzy sets (IFSs). IFSs took the degrees of membership and non-membership into consideration and could handle some ambiguity information. However, it was unable to cope with all the uncertainty issues in real life. Because the current decision-making is usually finished through voting at the meeting, thus there exists some particular situation that the neutral and reject are needed to consider independently (Deng et al., 2018; Gao et al., 2019; Li & Lu, 2019; Wang et al., 2019b; Wu et al., 2019a). In the previous fuzzy sets, it is difficult to depict the neutral and reject information. Therefore, in order to obtain more rigorous evaluation information, Cuong (2014) initiated the notion of picture fuzzy sets (PFSs) which took another described variable (neutral membership) into consideration. The PFSs have three described variables which are the degrees of membership, neutral membership and non-membership. The sum of the three described variables cannot exceed 1. Garg (2017) defined the PFWA and PFOWA operators. Zhang et al. (2018) found novel Dombi operations and Heronian mean (HM) to integrate with PFNs. Tian et al. (2019) put forward several operators which can consider the interrelationship among criteria. Wang et al. (2020b) presented a bounded rationality behavioural model with PFNs to address MCDM issues. Jin et al. (2019) developed a model which was related to Pearson's picture fuzzy correlation for MCDM analysis. Son (2017) extended the fundamental distance measure in the context of PFSs. Son (2016) presented the gengeralized picture distance and linked it with Hierarchical Picture Clustering. Wang et al. (2018a) utilized the PFSs to formulate a framework which was related to hybrid FMADM to sort the EPC projects' risk factors. Liang et al. (2018) integrated the EDAS with ELECTRE module to infer the level of cleaner production. Ashraf et al. (2018) proposed the TOPSIS method to fuse the PFNs. Wang et al. (2018b) integrated the PFNP model with VIKOR method to tackle MCDM issues. Wei et al. (2019d) combined bidirectional projection with PFSs to tackle some MCDM issues. Arya and Kumar (2020) designed an algorithm for PFS with the help of TODIM and VIKOR methods to explain the MCDM issues with PFNs. Lin et al. (2020) developed picture fuzzy MULTIMOORA method relying on the modified score function and Borda rule to process the issue that selected the car sharing stations site in Beijing. Cao (2020) utilized TOPSIS method and biparametric picture fuzzy distance measure to construct a MCDM model for GSS. Wang et al. (2020a) presented picture fuzzy TOPSIS-based QUALIFLEX method to tackle BEER project selection issue.

The COPRAS method was initially presented by Zavadskas et al. (1994), which was utilized to cope with information more efficient. Keshavarz Ghorabaee et al. (2014) ranked the IT2FNs by using COPRAS method and group decision-making with IT2FNs. Bausys et al. (2015) gave COPRAS method within the single-value neutrosophic numbers. Makhesana (2015) utilized the COPRAS method to select fast prototyping process. Rathi and Balamohan (2017) utilized COPRAS method for fuzzy MAGDM. Chatterjee and Kar (2018) selected the telecom supplier by using fuzzy-based COPRAS-G method. Darko and Liang (2020) utilized the Maclaurin symmetric mean (MSM), the dual MSM (DMSM) and COPRAS method to design a novel method for the dual hesitant fuzzy MAGDM. Yucenur et al. (2020) presented a novel method which obtained criteria weight with SWARA method and selected appropriate city to establish a biogas facility by using COPRAS method.

2. Preliminaries

2.1. Picture fuzzy sets

Definition 1 (Cuong, 2014). A picture fuzzy set (PFS) on the universe $X$is defined

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

where $\mu_A(x)\in[0,1]$ is represented the "positive membership degree of A", $\eta_A(x)\in[0,1]$ is represented the "neutral membership degree of A" and $\nu_A(x)\in[0,1]$ is represented the "negative membership degree of A", in addition, $\mu_A(x)$, $\eta_A(x)$, $\nu_A(x)$ must meet the condition: $0\le\mu_A(x)+\eta_A(x)+\nu_A(x)\le 1,\ \forall x\in X$. Then for $x\in X$, $\pi_A(x)=1-\left(\mu_A(x)+\eta_A(x)+\nu_A(x)\right)$ is represented the refusal membership degree of x in A.

Definition 2 (Wang et al., 2017). Let $\alpha=(\mu_\alpha,\eta_\alpha,\nu_\alpha)$ and $\beta=(\mu_\beta,\eta_\beta,\nu_\beta)$ be any two picture fuzzy numbers (PFNs), the operational formula of PFNs can be given:

$$\alpha\oplus\beta=\left(1-(1-\mu_\alpha)(1-\mu_\beta),\eta_\alpha\eta_\beta,(\nu_\alpha+\eta_\alpha)(\nu_\beta+\eta_\beta)-\eta_\alpha\eta_\beta\right); \tag{2}$$

$$\alpha\otimes\beta=\left((\mu_\alpha+\eta_\alpha)(\mu_\beta+\eta_\beta)-\eta_\alpha\eta_\beta,\eta_\alpha\eta_\beta,1-(1-\nu_\alpha)(1-\nu_\beta)\right); \tag{3}$$

$$\lambda\alpha=\left(1-(1-\mu_\alpha)^\lambda,\eta_\alpha^\lambda,(\nu_\alpha+\eta_\alpha)^\lambda-\eta_\alpha^\lambda\right),\lambda>0; \tag{4}$$

$$\alpha^\lambda=\left((\mu_\alpha+\eta_\alpha)^\lambda-\eta_\alpha^\lambda,\eta_\alpha^\lambda,1-(1-\nu_\alpha)^\lambda\right),\lambda>0. \tag{5}$$

Definition 3 (Cuong, 2014). Let $\alpha=(\mu_\alpha,\eta_\alpha,\nu_\alpha)$ and $\beta=(\mu_\beta,\eta_\beta,\nu_\beta)$ be any two PFNs, the score and accuracy functions of α and β can be expressed respectively:

$$S(\alpha)=\mu_\alpha-\nu_\alpha,S(\beta)=\mu_\beta-\nu_\beta; \tag{6}$$

$$H(\alpha)=\mu_\alpha+\eta_\alpha+\nu_\alpha,H(\beta)=\mu_\beta+\eta_\beta+\nu_\beta. \tag{7}$$

For two PFNs α and β, based on the Definition 3, then

(1) *if* $s(\alpha)<s(\beta)$, then $\alpha<\beta$;
(2) *if* $s(\alpha)=s(\beta),h(\alpha)<h(\beta)$, then $\alpha<\beta$;
(3) *if* $s(\alpha)=s(\beta),h(\alpha)=h(\beta)$, then $\alpha=\beta$.

2.2. Picture fuzzy aggregation operators

In this part, the PFWA operator and PFWG operator are introduced.

Definition 4 (Wang et al., 2017). Let $\alpha_j=\left(\mu_{\alpha_j},\eta_{\alpha_j},\nu_{\alpha_j}\right)(j=1,2,\cdots,n)$ be a set of PFNs. The PFWA operator can be depicted in the following:

$$\mathrm{PFWA}_\omega(\alpha_1,\alpha_2,\ldots,\alpha_n)=\mathop{\oplus}_{j=1}^{n}\left(\omega_j\alpha_j\right), \tag{8}$$

where $\omega=(\omega_1,\omega_2,\ldots,\omega_n)^T$ be the weight of $\alpha_j\ (j=1,2,\ldots,n)$, $\omega_j>0,\sum_{j=1}^{n}\omega_j=1$.

The subsequently **Theorem 1** can be derived based on Definition 4:

Theorem 1. The fused value by utilizing PFWA operator is also a PFN, and

$$PFWA_{\omega}(\alpha_1,\alpha_2,\ldots,\alpha_n)=\overset{n}{\underset{j=1}{\oplus}}\left(\omega_j\alpha_j\right)=$$

$$\left(1-\prod_{j=1}^{n}\left(1-\mu_{\alpha_j}\right)^{\omega_j},\prod_{j=1}^{n}\left(\eta_{\alpha_j}\right)^{\omega_j},\prod_{j=1}^{n}\left(\nu_{\alpha_j}+\eta_{\alpha_j}\right)^{\omega_j}-\prod_{j=1}^{n}\left(\eta_{\alpha_j}\right)^{\omega_j}\right), \tag{9}$$

where $\omega=\left(\omega_1,\omega_2,...,\omega_n\right)^T$ be the weight of $\alpha_j\left(j=1,2,...,n\right)$, $\omega_j>0,\sum_{j=1}^{n}\omega_j=1.$

Definition 5 (Wang et al., 2017). Let $\alpha_j\left(j=1,2,\cdots,n\right)$ be a set of PFNs. The PFWG operator is introduced as:

$$PFWG_{\omega}(\alpha_1,\alpha_2,\ldots,\alpha_n)=\overset{n}{\underset{j=1}{\otimes}}\left(\alpha_j\right)^{\omega_j}, \tag{10}$$

where $\omega=\left(\omega_1,\omega_2,...,\omega_n\right)^T$ be the weight of $\alpha_j\left(j=1,2,...,n\right)$, $\omega_j>0,\sum_{j=1}^{n}\omega_j=1.$

On the basis of the Definition 5, the following result can be derived:

Theorem 2. The fused value by utilizing PFWG operator is also a PFN, and

$$PFWG_{\omega}(\alpha_1,\alpha_2,\ldots,\alpha_n)=\overset{n}{\underset{j=1}{\otimes}}\left(\alpha_j\right)^{\omega_j}=$$

$$\left(\prod_{j=1}^{n}\left(\mu_{\alpha_j}+\eta_{\alpha_j}\right)^{\omega_j}-\prod_{j=1}^{n}\left(\eta_{\alpha_j}\right)^{\omega_j},\prod_{j=1}^{n}\left(\eta_{\alpha_j}\right)^{\omega_j},1-\prod_{j=1}^{n}\left(1-\nu_{\alpha_j}\right)^{\omega_j}\right), \tag{11}$$

where $\omega=\left(\omega_1,\omega_2,...,\omega_n\right)^T$ be the weight of $\alpha_j\left(j=1,2,...,n\right)$, $\omega_j>0,\sum_{j=1}^{n}\omega_j=1.$

3. COPRAS method for picture fuzzy MAGDM problems

The COPRAS method has been widely investigated in many MAGDM problems. The COPRAS method with PFSs is built to solve this kind of MAGDM problems. Assume that we have m alternatives $\{P_1,P_2,\ldots P_m\}$, n attributes $\{Q_1,Q_2,\ldots Q_n\}$ and l experts $\{t_1,t_2,\ldots t_l\}$, let $\{q_1,q_2,\ldots q_n\}$ and $\{\psi_1,\psi_2,\ldots\psi_l\}$ be the weighting vector of attributes and experts respectively which meet $q_j\in\left[0,1\right],\psi_k\in\left[0,1\right]$ and $\sum_{j=1}^{n}q_j=1,\sum_{k=1}^{l}\psi_k=1.$

The developed model's calculating procedures can be depicted in the following way.

Step 1. Build each DM's picture fuzzy assessing matrix $H^{(k)}=\left(h_{ij}^{k}\right)_{m\times n}$ and calculate the group picture fuzzy assessing matrix $H=\left(h_{ij}\right)_{m\times n}$.

$$H^{(k)}=\left[h_{ij}^{k}\right]_{m\times n}=\begin{bmatrix} h_{11}^{k} & h_{12}^{k} & \cdots & h_{1n}^{k} \\ h_{21}^{k} & h_{22}^{k} & \cdots & h_{2n}^{k} \\ \vdots & \vdots & \vdots & \vdots \\ h_{m1}^{k} & h_{m2}^{k} & \cdots & h_{mn}^{k} \end{bmatrix}; \tag{12}$$

$$H = \left[h_{ij}\right]_{m\times n} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1n} \\ h_{21} & h_{22} & \cdots & h_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ h_{m1} & h_{m2} & \cdots & h_{mn} \end{bmatrix}; \tag{13}$$

$$h_{ij} = \left(1 - \prod_{k=1}^{l}\left(1-\mu_{\alpha_{ij}^k}\right)^{\psi_k}, \prod_{k=1}^{l}\left(\eta_{\alpha_{ij}^k}\right)^{\psi_k}, \prod_{k=1}^{l}\left(\nu_{\alpha_{ij}^k}+\eta_{\alpha_{ij}^k}\right)^{\psi_k} - \prod_{k=1}^{l}\left(\eta_{\alpha_{ij}^k}\right)^{\psi_k}\right), \tag{14}$$

where h_{ij}^k is the assessing value of $P_i\left(i=1,2,\ldots,m\right)$ on the basis of the attribute $Q_j\left(j=1,2,\ldots,n\right)$ and the decision maker $t_k\left(k=1,2,\ldots,l\right)$, m illustrates the alternatives numbers and n illustrates the attributes numbers and k illustrates the DMs numbers.

Step 2. Decide the weighting matrix by using the CRITIC method.

Determining the criteria weight is viewed as a significant part in processing the MAGDM issues. Different criteria may have different weights and different criteria weights may lead to different results. For experts, it is difficult to obtain accurate and objective weight values from the real data. Because the process of acquiring weight values is complicated and the experts may be influenced by their knowledge and biases. Therefore, as an objective method, CRITIC (CRiteria Importance Through Intercriteria Correlation) method is a great choice to avoid these issues. In this method, different criteria's weights can be calculated relying on the amount of information they contain, which can obtain the objective criteria weights and avoid subjective evaluation. This objective weighting method was firstly developed by Diakoulaki et al. (1995), taking both the importance itself and the conflict caused by inter-criteria correlations into consideration when measure a criterion. Subsequently, we will present the computing procedures of this method.

① Depending on the average picture fuzzy decision matrix $H = \left[h_{ij}\right]_{m\times n} = \sum_{k=1}^{l}\left(\psi_k h_{ij}^k\right)$, the correlation coefficient matrix $\varphi = \left(\tau_{jt}\right)_{n\times n}$ is built by computing the correlation coefficient between attributes.

$$\tau_{jt} = \frac{\sum_{i=1}^{m}\left(S\left(h_{ij}\right)-S\left(h_j\right)\right)\left(S\left(h_{it}\right)-S\left(h_t\right)\right)}{\sqrt{\sum_{i=1}^{m}\left(S\left(h_{ij}\right)-S\left(h_j\right)\right)^2}\sqrt{\sum_{i=1}^{m}\left(S\left(h_{it}\right)-S\left(h_t\right)\right)^2}},\ j,t=1,2,\ldots,n, \tag{15}$$

where $S\left(h_j\right) = \frac{1}{m}\sum_{i=1}^{m}S\left(h_{ij}\right)$ and $S\left(h_t\right) = \frac{1}{m}\sum_{i=1}^{m}S\left(h_{it}\right)$.

② Compute each attribute's standard deviation.

$$\varsigma_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(S\left(h_{ij}\right)-S\left(h_j\right)\right)^2},\ j=1,2,\ldots,n, \tag{16}$$

where $S\left(h_j\right) = \frac{1}{m}\sum_{i=1}^{m}S\left(h_{ij}\right)$.

③ Compute each attribute's weight.

$$q_j = \frac{\varsigma_j \sum_{t=1}^{n}\left(1-\tau_{jt}\right)}{\sum_{j=1}^{n}\left(\varsigma_j \sum_{t=1}^{n}\left(1-\tau_{jt}\right)\right)}, j=1,2\ldots,n, \tag{17}$$

where $q_j \in [0,1]$ and $\sum_{j=1}^{n} q_j = 1$.

Step 3. Set up the weighted normalized assessing matrix $D=\left(d_{ij}\right)_{m\times n}$.

$$d_{ij} = h_{ij} \times q_j, i=1,2,\ldots,m, j=1,2,\ldots,n. \tag{18}$$

Step 4. Sum up the evaluation values of attributes for benefit and cost respectively.

$$R_i^+ = \sum_{j=1}^{n} d_{ij}^+ = \left(1-\prod_{j=1}^{n}\left(1-\mu_{d_{ij}^+}\right), \prod_{j=1}^{n}\eta_{d_{ij}^+}, \prod_{j=1}^{n}\left(\nu_{d_{ij}^+}+\eta_{d_{ij}^+}\right)-\prod_{j=1}^{n}\eta_{d_{ij}^+}\right); \tag{19}$$

$$R_i^- = \sum_{j=1}^{n} d_{ij}^- = \left(1-\prod_{j=1}^{n}\left(1-\mu_{d_{ij}^-}\right), \prod_{j=1}^{n}\eta_{d_{ij}^-}, \prod_{j=1}^{n}\left(\nu_{d_{ij}^-}+\eta_{d_{ij}^-}\right)-\prod_{j=1}^{n}\eta_{d_{ij}^-}\right). \tag{20}$$

Step 5. Determine the scores of each alternative according to benefit attributes and cost attributes.

$$O_i = S\left(R_i^+\right) + \frac{S\left(R_{\min}^-\right)\sum_{i=1}^{m} S\left(R_i^-\right)}{S\left(R_i^-\right)\sum_{i=1}^{m}\frac{S\left(R_{\min}^-\right)}{S\left(R_i^-\right)}} = S\left(R_i^+\right) + \frac{\sum_{i=1}^{m} S\left(R_i^-\right)}{S\left(R_i^-\right)\sum_{i=1}^{m}\frac{1}{S\left(R_i^-\right)}}. \tag{21}$$

The priority of each alternative O_i and P_i^+ are positive correlated, while O_i and P_i^- are negative correlated.

Step 6. Compute the utility degree G_i.

$$G_i = \frac{O_i}{O_{\max}} \times 100\%, \tag{22}$$

where O_i and $O_{\max} = \max_i\left\{O_i\right\}$ are the significance degrees of alternatives, the higher value of G_i, the more preference of the alternative P_i.

4. The empirical example and comparative analysis

4.1. An empirical example for MAGDM issues with PFNs

In current society, due to the severe environmental issues and continuous consumption of fossil fuels, the demanding to develop new energy power generation projects is urgent. To comprehensive assess these projects, some objective assessment approaches are needed, so that the superiorities and slipups of these projects can be identified respectively and several proposals for them can be presented. Until now, some methods have attained achievements in new energy generation projects evaluation. Unfortunately, almost of them utilize a particular method to make a singular evaluation. Whereas, some guiding principles for multiple objective overall assessment methods have not yet came into being (Gao et al., 2020; He et al., 2019; Lu & Wei, 2019; Wang, 2019; Wei et al., 2019c; Wu et al., 2019b). Green supplier selection is a classical MAGDM problem (Zavadskas et al., 2018; Matić et al., 2019; Soheilirad et al., 2018; Yu et al., 2019). In this part, an application should be provided to select the optimal green supplier by utilizing COPRAS method with picture fuzzy information. Considering its own business development, a company wants to select a green supplier for long-term cooperation. There are five potential green suppliers $P_i\left(i=1,2,3,4,5\right)$. To select the optimal supplier, three experts $\mathrm{T}=\left\{t_1,t_2,t_3\right\}$ (expert's weight $\psi=\left(0.27,0.40,0.33\right)$) are invited to evaluate these suppliers. All the experts give their evaluation information on the basis of the four attributes: ① Q_1 is resource consumption; ② Q_2 is delivery cost; ③ Q_3 is green environmental protection ability; ④ Q_4 is eco-design. Obviously, Q_1 and Q_2 are cost attributes, while Q_3 and Q_4 are benefit attributes. To get the most appropriate supplier, the following procedures are involved:

Step 1. Set up the evaluation matrix $H^{(k)}=\left(h_{ij}^k\right)_{m\times n}\left(i=1,2,\ldots,m, j=1,2,\ldots,n\right)$ of each DM as in Tables 1–3. On the basis of these tables and Eqs (12) to (14), the average picture fuzzy decision matrix may be computed. The calculating results are listed in Table 4.

Table 1. Picture fuzzy assessing information by DM_1

	Q_1	Q_2	Q_3	Q_4
P_1	(0.34, 0.41, 0.25)	(0.42, 0.24, 0.34)	(0.24, 0.40, 0.36)	(0.25, 0.27, 0.48)
P_2	(0.65, 0.20, 0.15)	(0.57, 0.25, 0.18)	(0.72, 0.14, 0.14)	(0.49, 0.31, 0.20)
P_3	(0.39, 0.36, 0.25)	(0.51, 0.18, 0.31)	(0.39, 0.28, 0.33)	(0.43, 0.35, 0.22)
P_4	(0.62, 0.18, 0.20)	(0.37, 0.38, 0.25)	(0.61, 0.22, 0.17)	(0.13, 0.41, 0.46)
P_5	(0.46, 0.23, 0.31)	(0.66, 0.15, 0.19)	(0.53, 0.26, 0.21)	(0.25, 0.39, 0.36)

Table 2. Picture fuzzy evaluation information by DM_2

	Q_1	Q_2	Q_3	Q_4
P_1	(0.31, 0.29, 0.40)	(0.47, 0.33, 0.20)	(0.37, 0.30, 0.33)	(0.56, 0.28, 0.16)
P_2	(0.59, 0.25, 0.16)	(0.34, 0.38, 0.28)	(0.69, 0.21, 0.10)	(0.50, 0.26, 0.24)
P_3	(0.41, 0.36, 0.23)	(0.22, 0.35, 0.43)	(0.52, 0.33, 0.15)	(0.16, 0.37, 0.47)
P_4	(0.42, 0.38, 0.20)	(0.55, 0.21, 0.24)	(0.64, 0.17, 0.19)	(0.14, 0.40,0.46)
P_5	(0.54, 0.28, 0.18)	(0.47, 0.28, 0.25)	(0.43, 0.25, 0.32)	(0.25, 0.38, 0.37)

Table 3. Picture fuzzy evaluation information by DM_3

	Q_1	Q_2	Q_3	Q_4
P_1	(0.48, 0.27, 0.25)	(0.52, 0.28, 0.20)	(0.33, 0.34, 0.33)	(0.49, 0.22, 0.29)
P_2	(0.66, 0.19, 0.15)	(0.57, 0.23, 0.20)	(0.44, 0.37, 0.19)	(0.80, 0.10, 0.10)
P_3	(0.37, 0.41, 0.22)	(0.62, 0.21, 0.17)	(0.15, 0.35, 0.50)	(0.56, 0.28, 0.16)
P_4	(0.51, 0.18, 0.31)	(0.18, 0.31, 0.51)	(0.49, 0.27, 0.24)	(0.37, 0.27, 0.36)
P_5	(0.42, 0.28, 0.30)	(0.42, 0.36, 0.22)	(0.51, 0.20, 0.29)	(0.60, 0.26, 0.14)

Table 4. Average picture fuzzy decision matrix

	Q_1	Q_2	Q_3	Q_4
P_1	(0.3790, 0.3110, 0.3100)	(0.4744, 0.2868, 0.2388)	(0.3237, 0.3379, 0.3384)	(0.4665, 0.2561, 0.2775)
P_2	(0.6307, 0.2150, 0.1543)	(0.4896, 0.2876, 0.2228)	(0.6334, 0.2269, 0.1397)	(0.6285, 0.1989, 0.1726)
P_3	(0.3916, 0.3758, 0.2326)	(0.4574, 0.2471, 0.2955)	(0.3816, 0.3219, 0.2965)	(0.3889, 0.3325, 0.2787)
P_4	(0.5106, 0.2427, 0.2467)	(0.3993, 0.2803, 0.3204	(0.5873, 0.2123, 0.2004)	(0.2215, 0.3537, 0.4248)
P_5	(0.4815, 0.2655, 0.2530)	(0.5157, 0.2570, 0.2273)	(0.4853, 0.2347, 0.2800)	(0.3905, 0.3376, 0.2719)

Step 2. Calculate the attributes weights $q_j\left(j=1,2,\ldots,n\right)$ by utilizing the Eqs (15) to (17) as listed in Table 5.

Table 5. The attributes weights q_j

	Q_1	Q_2	Q_3	Q_4
q_j	0.2046	0.1685	0.3933	0.2336

Step 3. Compute the weighted normalized assessing matrix $D=\left(d_{ij}\right)_{m\times n}$ as listed in the Table 6.

Table 6. The weighted normalized assessing matrix D

	Q_1	Q_2	Q_3	Q_4
P_1	(0.0929, 0.7875, 0.1197)	(0.1027, 0.8102, 0.0871)	(0.1426, 0.6526, 0.2048)	(0.1365, 0.7274, 0.1361)
P_2	(0.1843, 0.7302, 0.0855)	(0.1071, 0.8106, 0.0823)	(0.3261, 0.5580, 0.1159)	(0.2065, 0.6857, 0.1078)
P_3	(0.0967, 0.8186, 0.0848)	(0.0979, 0.7901, 0.1120)	(0.1723, 0.6403, 0.1875)	(0.1087, 0.7732, 0.1182)
P_4	(0.1360, 0.7485, 0.1155)	(0.0823, 0.8071, 0.1106)	(0.2940, 0.5436, 0.1624)	(0.0568, 0.7844, 0.1588)
P_5	(0.1257, 0.7624, 0.1119)	(0.1150, 0.7954, 0.0896)	(0.2299, 0.5655, 0.2046)	(0.1092, 0.7760, 0.1148)

Step 4. Sum up the benefit and cost attributes by using the Eqs (19) and (20).

$$R_1^- =\left(0.1860, 0.6380, 0.1759\right),\ R_2^- =\left(0.2717, 0.5919, 0.1364\right),$$
$$R_3^- =\left(0.1851, 0.6468, 0.1681\right),\ R_4^- =\left(0.2071, 0.6041, 0.1888\right),$$
$$R_5^- =\left(0.2262, 0.6064, 0.1673\right);$$
$$R_1^+ =\left(0.2596, 0.4747, 0.2657\right),\ R_2^+ =\left(0.4653, 0.3826, 0.1521\right),$$
$$R_3^+ =\left(0.2622, 0.4950, 0.2428\right),\ R_4^+ =\left(0.3341, 0.4264, 0.2395\right),$$
$$R_5^+ =\left(0.3140, 0.4388, 0.2472\right).$$

Step 5. Calculate each alternative's significance by utilizing the Eq. (21).

$$O_1 = 0.0939, O_2 = 0.3207, O_3 = 0.0792, O_4 = 0.1499, O_5 = 0.0840.$$

Step 6. Calculate the G_i by using the Eq. (22).

$$G_1 = 0.2929, G_2 = 1.0000, G_3 = 0.2470, G_4 = 0.4674, G_5 = 0.2618.$$

Step 7. Relying on the calculating results of G_i, all alternatives are ranked. The higher value of G_i is, the optimal alternative choice will be. Apparently, all alternatives' order is $P_2 > P_4 > P_1 > P_5 > P_3$ and P_2 is the optimal alternative.

4.2. Comparative analysis

In this part, a comparison is made between the designed method and some existed approaches to demonstrate the superiority of our method. To begin with, our designed method is compared with PFWA and PFWG operators (Wang et al., 2017). For the PFWA operator, the calculating result is $S(P_1) = -0.0080$, $S(P_2) = 0.2361$, $S(P_3) = 0.0025$, $S(P_4) = 0.0800$, $S(P_5) = 0.0285$. Thus, the ranking order is $P_2 > P_4 > P_5 > P_3 > P_1$. For the PFWG operator, the calculating result is $S(P_1) = -0.0203$, $S(P_2) = 0.0869$, $S(P_3) = -0.0052$, $S(P_4) = 0.0187$, $S(P_5) = -0.0033$. So the ranking order is $P_2 > P_4 > P_5 > P_3 > P_1$.

What's more, the designed method is compared with PF-TODIM method (Liang et al., 2018). Then the calculating result can be obtained. The dominance degree of P_i over other alternative P_t is:

$$\delta(P_i, P_t) = \begin{bmatrix} 0.0000 & -0.5814 & -0.2217 & -0.3542 & 0.0457 \\ -0.1648 & 0.0000 & -0.3177 & -0.3008 & 0.1219 \\ -0.3470 & -0.5746 & 0.0000 & -0.2924 & -0.0846 \\ -0.4737 & -0.5713 & -0.4431 & 0.0000 & -0.2735 \\ -0.6446 & -0.8496 & -0.4435 & -0.3944 & 0.0000 \end{bmatrix}.$$

And then the overall dominance values of alternatives are $\delta(P_1) = 0.7306$, $\delta(P_2) = 1.0000$, $\delta(P_3) = 0.6187$, $\delta(P_4) = 0.3414$, $\delta(P_5) = 0.0000$. Hence, the ranking order of alternatives is $P_2 > P_1 > P_3 > P_4 > P_5$.

Additionally, our presented method is compared with picture fuzzy cross-entropy (Wei, 2016). Each alternative's ranking index is decided as: $C(P_1, P^+) = 0.0409$, $C(P_2, P^+) = 0.0124$, $C(P_3, P^+) = 0.0373$, $C(P_4, P^+) = 0.0372$, $C(P_5, P^+) = 0.0249$. Thus, the ranking order is $P_2 > P_5 > P_4 > P_3 > P_1$.

Besides, our presented method is compared with Picture Fuzzy projection model (Wei et al., 2018). Each alternative's ranking index is decided as: $Prj_{P^+}(P_1) = 0.2723$, $Prj_{P^+}(P_2) = 0.3520$, $Prj_{P^+}(P_3) = 0.2788$, $Prj_{P^+}(P_4) = 0.3107$, $Prj_{P^+}(P_5) = 0.3014$. Thus, the ranking order is $P_2 > P_4 > P_5 > P_3 > P_1$.

Eventually, these methods' results are recorded in Table 7.

In the light of the Table 7, it is evidently that the most appropriate supplier is P_2 in the all mentioned methods, which demonstrates that the designed method in this article is feasible. And in most situation, the worst choice is P_1. That's to say, there exist some differentiations in ranking results of these methods. Compare with these methods, the developed method is more superiority. The reasons can be illustrated as follows.

Table 7. Evaluation results of dissimilar methods

Methods	Ranking order	The optimal alternative	The worst alternative
PFWA	$P_2 > P_4 > P_5 > P_3 > P_1$	P_2	P_1
PFWG	$P_2 > P_4 > P_5 > P_3 > P_1$	P_2	P_1
TODIM	$P_2 > P_1 > P_3 > P_4 > P_5$	P_2	P_5
Cross-entropy	$P_2 > P_5 > P_4 > P_3 > P_1$	P_2	P_1
Projection models	$P_2 > P_4 > P_5 > P_3 > P_1$	P_2	P_1
The developed method	$P_2 > P_4 > P_1 > P_5 > P_3$	P_2	P_3

(1) The PFWA and PFWG operators just simply rank the potential green suppliers by utilizing the fused PFNs. And they don't take the conflicting relationships between criteria into account.
(2) The PF-TODIM method ranks all the potential green suppliers by utilizing the dominance degree of each alternative over another one. Due to the criteria weights are given in advance, the ranking results may change because of the change of weight distribution of criteria.
(3) The picture fuzzy cross-entropy method ranks all the potential green suppliers by measuring the discrimination degree of each alternative against the ideal point. Though it is easy to identify the optimal supplier, but the evaluation results are not stable. Because the criteria weights are also given in advance, which may cause the ranking results change because of the change of weight distribution of criteria.
(4) The picture fuzzy projection model ranks all the potential green suppliers by calculating the similarity degree between each alternative and ideal solution. Although this method can get rid of the deviation caused by the different assessment dimensions of the DMs, it doesn't take the conflicting relationships between criteria into account.
(5) Our proposed method ranks all the potential green suppliers by determining the proportional dependence of significance and priority of alternatives with regard to criteria, which is essential for DMs to compute the amount of efficiency for one alternative towards another. Besides, an objective method is utilized to compute criteria weights. These make the assessment results are more accurate and stable than the existing four methods. In addition, the proposed method can also be applied to many other uncertain environments (Lu et al., 2020; Wei et al., 2019a, 2019b) and ambiguous environments (Erdogan et al., 2019; Roy et al., 2019; Stanujkic et al., 2019; Zavadskas et al., 2019a, 2019b).

Conclusions

GSS is of great significance in the process of enterprise production, management and competition. Hence, it is imperative for enterprises to employ an effective green supplier evaluation system. This paper integrates COPRAS method with PFSs to solve the MAGDM problem for choosing the most appropriate green supplier. After that providing a practical application shows that the designed method is reasonable. In addition, to verify the developed method's validity and feasibility, several comparative analysis is also offered. However, the main drawback of this paper is that the number of DMs and attributes are insufficient and attributes' interdependency is not pondered, which may limit the developed method's application scope to some extent. Future research can tackle the interdependency of attributes by utilizing some methods including ANP and AHP methods. Furthermore, the developed method can be utilized to tackle many other MAGDM issues like risk evaluation, project selection and site selection.

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