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Authors: Ahmet Selcuk Yalcin, Huseyin Selcuk Kilic
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Green Supplier Selection via an Integrated Multi-Attribute Decision Making Approach

Ahmet Selcuk Yalcin[1], Huseyin Selcuk Kilic*[2]

Abstract

The environmental awareness of society and the global competition market has increased significantly due to the environmental problems that happen today. Companies have recognized the importance of focusing on environmental issues in order to be strong in a modern competitive business environment. Therefore, environmental factors are taken into consideration during the supplier selection process, which is an important decision point in the supply chain. In this study, two robust multi-attribute decision making techniques, Intuitionistic Fuzzy AHP (IF-AHP) and PROMETHEE, are used in an integrated way to better handle this selection problem. The steps are clearly explained in the proposed methodology. First, the relative weights of the criteria are determined by IF-AHP, which allows decision makers (DMs) to deal with the uncertainty of the evaluation process. Subsequently, the weights of criteria obtained are used in the PROMETHEE method for the best ranking of alternative suppliers. An application is performed in the air filtration industry to demonstrate the validity of the proposed method.

Keywords: Greenness, IF-AHP, PROMETHEE, Supplier selection

1.INTRODUCTION

The examination and management of industrial wastes has been a serious issue for society since the industrial revolution took place [1]. Especially after 80's, toxic gases and wastes produced by factories have reached serious dimensions which threaten human health. In the 90s, the protection of natural resources and the environment has become a very important global problem at national and international conferences [2]. Suppliers with environmental awareness are preferred by firms because the firms can better adapt to the global environmental trend and create an impressive green image. In addition, another reason is that harmful compounds contained in the raw materials and semi-products provided by the supplier may lead to significant environmental effects in the whole process [3]. Thus, determining the environmentally conscious supplier can be regarded as one of the most significant activities in the supply chain (SC). As globalization grows, supplier selection problem becomes more complex. This problem has become a multi-criteria decision-making problem that requires many variables, environmental and

[1] Okan University, Industrial Engineering, Istanbul, Turkey. ORCID: 0000-0001-8963-0604
* Corresponding Author: huseyin.kilic@marmara.edu.tr
[2] Marmara University, Industrial Engineering, Istanbul, Turkey. ORCID: 0000-0003-3356-0162

traditional criteria and alternatives to be jointly evaluated. DMs may be unsuccessful or reluctant in the assessment stage due to their limited information or the subjectivity of qualitative evaluation criteria. This cause ambiguity and uncertainty in the problem [4,5]. In this paper, IF-AHP is regarded as a suitable method to detect the significance weights of main and sub criteria because it is easy to implement in spite of the ambiguity of human decision. Afterwards, PROMETHEE II method is utilized to rank the alternatives. An implementation is realized in a filtration plant to demonstrate the steps of the suggested model as indicated in Figure 1.

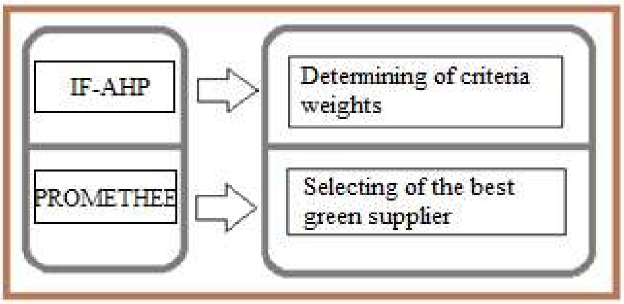

Figure 1. Summary of the study

The objective of the study is to propose a methodology to determine the most appropriate environmentally conscious supplier considering green and conventional criteria. The contributions of this research to the literature are summarized as follows:

- A consensus is made between DMs to prevent time waste when pairwise comparison is made between criteria.
- IF-AHP method which is novel in the literature has been used to weight the criteria
- The proposed methodology has been applied in a case study of the filtration industry, which has never been studied before.
- Since criteria play an important role and change with respect to the sector, the green and classic criteria used in this study were determined considering the filter industry.

The rest of this paper is organized as follows: Section two presents a literature review of green supplier selection methods and criteria. In the third section, the proposed method is explained in detail. In the fourth part, the application of the method suggested in a real case study is introduced. In the last section, the results of the study are discussed and recommendations are given for future studies.

2. LITERATURE REVIEW

In this section, a literature review of the criteria and techniques used in the green supplier selection studies was conducted.

2.1. Green Supplier Selection Criteria

Evaluation of the criteria is the first step in green supplier selection process. The contingency of obtaining misleading and incorrect results increases as long as the criteria are not properly determined. With growing environmental awareness, public and governmental pressures, executives have to buy from suppliers who are able to supply commodities and services with "lower price, higher quality, shorter lead time, and at the same time with focus on stronger environmental responsibility" [6]. In order to achieve long-term success and to select the best green suppliers in the modern market, companies and organizations should pay enough attention to both traditional and environmental factors. In the literature, in the determination of green and traditional criteria, researchers have often benefited from scientific journals, expert opinions and previous researches and so on.

Dickson analyzed 170 negotiations with the procurement directors and ranked 23 traditional criteria which are used in several studies. He introduced quality, delivery, performance history, warranties and claim policies as extremely important [7]. Weber et al. examined the 74 present reports to find out crucial factors in decision making problems and concluded that the most significant factors are price, delivery and quality [8]. Ho et al. illustrated that the most popular criteria are quality, followed by delivery, price/cost, manufacturing capability, service, management, technology, research and development (R&D), finance and flexibility [9]. Environmental management system (EMS), pollution control, green image, green design and solid or water waste are the most frequently used criteria respectively in the studies published after 2008. Govindan et al. identified EMS as the most important green criterion in the selection of green suppliers [10]. Similarly, Nielsen et al. examined 57 green supplier selection studies, concluded that EMS was used as an environmental criterion in about thirty-five percent of studies [11]. After investigating 34 published articles, Villanueva-Ponce et al. indicated green product design, GSCM, environmental management are the most frequently used ones [12]. Banasik et al. pointed out greenhouse gases as the most popular key performance indicator in the studies [13].

2.2. Green Supplier Selection Methods

An effective supplier selection is the first step of a successful organization and a strong supply chain management (SCM). The success of the supplier selection process has a crucial effect on the productivity and success of the entire SC. However, a large number of previous studies on this subject have indicated that the supplier selection is the most important factor in the achievement of SC. It affects directly the environmental performance of the producer. Nonetheless, as companies increasingly depend on their suppliers, structure and results of green supplier selection problem have become critical [14].

Many different methods have been used in the literature for the selection of green suppliers. After reviewing 123 scientific journals published between 2008 and 2012 in supplier selection, Chai et al. reported that the most frequently utilized decision makings techniques were AHP (24.39%), LP (15.44%), TOPSIS (14.63%), ANP (12.20%) and DEA (10.57%) [15]. In particular, AHP is the most preferred technique by researchers. In the 2005-2009 period, the use of AHP steadily increased and was frequently used in studies [16]. Noci applied the AHP-based approach in five steps to assess the environmental performance of suppliers [17]. Humphreys et al. developed a decision support tool to help organizations integrate environmental factors into the supplier selection process [18]. Lu et al. proposed AHP and fuzzy logic-based model to help the green supply chain designer select the desired design alternative to achieve minimum environmental impact [19]. Lee et al. first applied the Delphi method to differentiate the criteria, then applied fuzzy expanded AHP to assess the uncertainty of the expert opinion [20]. Bai and Sarkis implemented rough set theory to deal with data uncertainty, taking environmental, social and economic factors into account for the selection of green suppliers [21]. Büyüközkan and Çifci proposed a fuzzy group multi-criteria decision model for evaluation of sustainable supplier utilizing fuzzy ANP [22]. Kannan et al. suggested a combined approach for supplier selection and order allocation in the green SC using fuzzy AHP, fuzzy TOPSIS, and multi objective linear programming [23]. Dobos and Vörösmarty introduced an integrated method to select green suppliers using data envelopment analysis and composite indicators [24]. Freeman and Chen developed a combined model for selecting green suppliers in electronic machine manufacturing using the AHP-Entropy model based on the TOPSIS method [25]. Darabi and Haydari suggested an interval valued hesitant fuzzy ranking method based on group decision analysis to evaluate and select green supplier [26]. Yazdani et al. suggested a combined methodology to select the most appropriate supplier, taking into account various environmental performance requirements and criteria. Their methods are based on the DEMATEL, QFD and COPRAS approaches [27]. Banaeian et al. compared the implementation of three popular multi-criteria supplier selection methods (TOPSIS, VIKOR and GRA) in a fuzzy environment. The methods are utilized for green supplier evaluation and selection in agri-food industry [28].

None of the techniques used in supplier selection have been integrated with intuitionistic fuzzy logic, as it has been noticed in the literature review. To address this shortcoming and remove ambiguity in the decision-making process, an approach that incorporates IF-AHP and PROMETHEE techniques in an integrated manner is presented in this study.

3. PROPOSED METHODOLOGY

The proposed methodology for green supplier selection consists of two parts. Firstly, after the criteria used to evaluate the suppliers have been determined, the importance weights of these criteria are found by the IF-AHP approach. Then, the order of suppliers is realized by PROMETHEE method.

3.1. Intuitionistic Fuzzy AHP (IF-AHP)

The IF-AHP method, which results from the integration of the intuitionistic fuzzy (IF) logic and the AHP method, is a method aimed at overcoming the ambiguity caused by the decision maker's subjective decisions. The substantial feature of this method is to have capability to achieve uncertainty which is inherent in decision making problems. Due to the hesitation function, more current results could be effectively obtained. However, IF-AHP is more superior and effective than the other AHP models in the process of removing the uncertainties that emerge from the decision maker [5]. The terms of $\mu_{ij}, v_{ij}, \pi_{ij}$ indicate the degree of membership, non-membership, and hesitation, respectively. The steps of this approach are as follows [29]:

Step 1: The structure of the hierarchy for the assessment of the problem is created. The aim, criteria and alternatives are determined.

Step 2: The pairwise comparative measure of the Intuitionistic Fuzzy-AHP with the novel measure of the decision matrix of triangular intuitionistic fuzzy numbers (TIFNs) is scaled. DMs are asked to detect ratings utilizing the nine AHP linguistic scale from the "equally significant" to the "absolutely more significant" expression on the criteria of the supplier problem. The transformation of the choice numbers of AHP to the TIFNs is shown in Table 1 [29].

Step 3: DMs' weights are determined. The significance of DMs is evaluated as linguistic factors. The linguistic factors of DMs were demonstrated in Table 2. Equation (1) proposed by Boran et al. is utilized to detect the weight of a decision maker weight [30]. It is assumed that $D = (\mu_k, v_k, \pi_k)$ is the IF number of k[th] DM.

$$\lambda_k = \frac{\left(\mu_k + \pi_k \cdot \left(\frac{\mu_k}{\mu_k + v_k}\right)\right)}{\sum_{k=1}^{m}\left(\mu_k + \pi_k \cdot \left(\frac{\mu_k}{\mu_k + v_k}\right)\right)} \quad (1)$$

Step 4: The unified IF decision matrix based on DM is created. $R^{(k)} = (r_{ij}^{k})_{mxn}$ denotes an IF decision matrix of the kth DM. $\lambda = \{\lambda_1, \lambda_2, \dots, \lambda_n\}$ denotes the weight of the all decision-maker and $\sum_{m=1}^{t} \lambda = 1$. Every separate view must be fused into the group idea to form an unified IF decision matrix by implementing intuitionistic fuzzy weighted averaging operator (IFWA) proposed by Xu [31].

$$r_{ij} = IFWA_\lambda\left(r_{ij}^{(1)}, r_{ij}^{(2)}, \dots, r_{ij}^{(t)}\right) = \lambda_1 r_{ij}^{(1)} \oplus \lambda_2 r_{ij}^{(2)} \oplus \dots \oplus \lambda_t r_{ij}^{(t)},$$

$$= \begin{bmatrix} 1 - \prod_{k=1}^{t}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k}, \\ \prod_{k=1}^{t}\left(v_{ij}^{(k)}\right)^{\lambda_k}, \\ \prod_{k=1}^{t}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k} - \\ \prod_{k=1}^{t}\left(v_{ij}^{(k)}\right)^{\lambda_k} \end{bmatrix} \quad (2)$$

$$r_{ij} = (\mu_{ij}, v_{ij}, \pi_{ij},),$$

$$\mu_{ij} = 1 - \prod_{k=1}^{t}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k}$$

$$v_{ij} = \prod_{k=1}^{t}\left(v_{ij}^{(k)}\right)^{\lambda_k}$$

$$\pi_{ij} = \prod_{k=1}^{t}\left(1 - \mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{t}\left(v_{ij}^{(k)}\right)^{\lambda_k}$$

Step 5: The consistency ratio (CR) of the unified IF decision matrix is computed by Equation (3).

$$CR = \frac{((\lambda_{max} - n)/(n-1))}{R.I} \quad (3)$$

in which it is supposed that $(\lambda_{max} - n)$ is the mean valuation of hesitation degree (π_k) of the criteria and n denotes the dimension of matrix in the study. The valuation of random indices (RI) proposed by Saaty is demonstrated on Table 3 [32]. CR can be accepted if it does not pass 0.10. If the ratio is bigger than 0.10, the decision matrix must be evaluated as unstable.

Table 1. Transformation of the AHP choice numbers to TIFNs [29]

Choice on pairwise comparison	**AHP Choice Number**	**Reciprocal Choice Number**	**TIFNs**	**Reciprocal TIFNs**
Equally important	1	1	(0.02, 0.18, 0.80)	(0.02, 0.18, 0.80)
Intermediate value	2	½	(0.06, 0.23, 0.70)	(0.23, 0.06, 0.70)
Moderately more important	3	1/3	(0.13, 0.27, 0.60)	(0.27, 0.13, 0.60)
Intermediate value	4	¼	(0.22, 0.28, 0.50)	(0.28, 0.22, 0.50)
Strongly more important	5	1/5	(0.33, 0.27, 0.40)	(0.27, 0.33, 0.40)
Intermediate value	6	1/6	(0.47, 0.23, 0.30)	(0.23, 0.47, 0.30)
Very strong more important	7	1/7	(0.62, 0.18, 0.20)	(0.18, 0.62, 0.20)
Intermediate value	8	1/8	(0.80, 0.10, 0.10)	(0.10, 0.80, 0.10)
Extremely more important	9	1/9	(1.0, 0, 0)	(0, 1.0, 0)

Table 2. Linguistic factors for the significance of DMs [30]

Ling. var.	**TIFNs**
Very significant	(9/10, 5/100, 5/100)
Significant	(75/100, 20/100, 5/100)
Medium	(50/100, 40/100, 10/100)
Insignificant	(25/100, 60/100, 15/100)
Very insignificant	(10/100, 80/100, 10/100)

Table 3. Random indices of sizes of matrices [32]

n	**1-2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Step 6: The IF weight of the unified IF decision matrix is computed. Equation (4) is used to calculate the entropy weight of each criterion.

$$\bar{\bar{w}}_i = -\frac{1}{n \ln 2}[\mu_i \ln \mu_i + v_i \ln v_i - (1-\pi_i)\ln(1-\pi_i) - \pi_i \ln 2] \quad (4)$$

The final entropy weights of each criterion can be calculated using Equation (5). It is assumed that the sum of the criterion weights is equal to one.

$$w_i = \frac{1-\bar{\bar{w}}_i}{n-\sum_i^n \bar{\bar{w}}_i} \quad (5)$$

3.2. PROMETHEE

PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) is a multiple decision making method developed by Jean-Pierre Brans in 1982. This method is based on superiority. The steps of the PROMETHEE II method are as follows [33]:

Step 1: The data matrix is created. The data matrix is constructed by weights and alternatives which are evaluated by criteria.

Step 2: The preference functions for criteria are determined. They are determined to show the structure and internal relations of the identified evaluation factors. They are shown in Table 4.

Step 3: The common preference functions for the pair of alternatives based on preference functions are determined. The calculation of common preference function is indicated in Equation (6).

$$P(a,b) = \begin{cases} 0, f(a) \le f(b) \\ p[f(a)-f(b)], f(a) > f(b) \end{cases} \quad (6)$$

Table 4. Preference functions

Type	Parameter	Function
First type	-	$p(d) = \begin{cases} 0, d \leq 0 \\ 1, d > 0 \end{cases}$
Second type	m	$p(d) = \begin{cases} 0, d \leq m \\ 1, d > m \end{cases}$
Third type	k	$p(d) = \begin{cases} d/k, d \leq k \\ 1, d > k \end{cases}$
Fourth type	a, b	$p(d) = \begin{cases} 0, d \leq a \\ 1/2, a < d \leq b \\ 1, d > b \end{cases}$
Fifth type	c, e	$p(d) = \begin{cases} 0, d \leq c \\ d - c/_{e-c}, c < d \leq e \\ 1, d > e \end{cases}$
Sixth type	σ	$P(d) = \begin{cases} 0, d \leq 0 \\ 1 - e^{\frac{d^2}{2\sigma^2}}, d > 0 \end{cases}$

Step 4: The preference index for every pair of alternative is detected. The calculation of preference index for any a and b alternatives evaluated with respect to k criterion is done by using Equation (7).

$$\pi(a,b) = \frac{\sum_{i=1}^{k} W_i * P_i(a,b)}{\sum_{i=1}^{k} W_i} \quad (7)$$

Step 5: Positive and negative superiorities for alternatives are determined. The positive and negative priorities for alternative a could be computed by utilizing Equations (8) and (9) respectively.

$$\Phi^+(a) = \frac{1}{n-1} \sum_{i=1}^{n} \pi(a,b) \quad (8)$$

$$\Phi^-(a) = \frac{1}{n-1} \sum_{i=1}^{n} \pi(b,a) \quad (9)$$

Step 6: Complete priorities of alternatives with PROMETHEE II are determined. The complete priority of each alternative is calculated by the aid of Equations (10) - (12).

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \quad (10)$$

If $\Phi(a) > \Phi(b)$alternative a is more superior. (11)

If $\Phi(a) = \Phi(b)$ alternatives a and b are same. (12)

4. CASE STUDY

This section presents an implementation in the filtration industry to demonstrate the feasibility and validity of the integrated IF-AHP and PROMETHEE approaches. The suppliers in the application provide HEPA air filtration media. Five supplier alternatives were regarded as potential suppliers provided that they have environmental qualifications such as ISO 14001 and EU Eco-Management and Audit Scheme (EMAS). Those suppliers are called as A1, A2, A3, A4 and A5 because of the privacy policy of the companies. The criteria of the study are detected considering the recommendations of the experienced managers in the company. Accordingly, "quality", "price", "delivery", "flexibility" and "green" are the main criteria. "Green image", "recyclability of raw material", "design for disassembly and reuse", "green R & D" and "transportation" are the sub-criteria of "greenness". Three DMs who are executives of departments of quality, production and R&D have participated in the assessment process.

4.1. IF-AHP

IF-AHP mentioned in Section 3.1 is used to calculate the weights of the main and sub criteria. Only the calculation of the main criteria has been

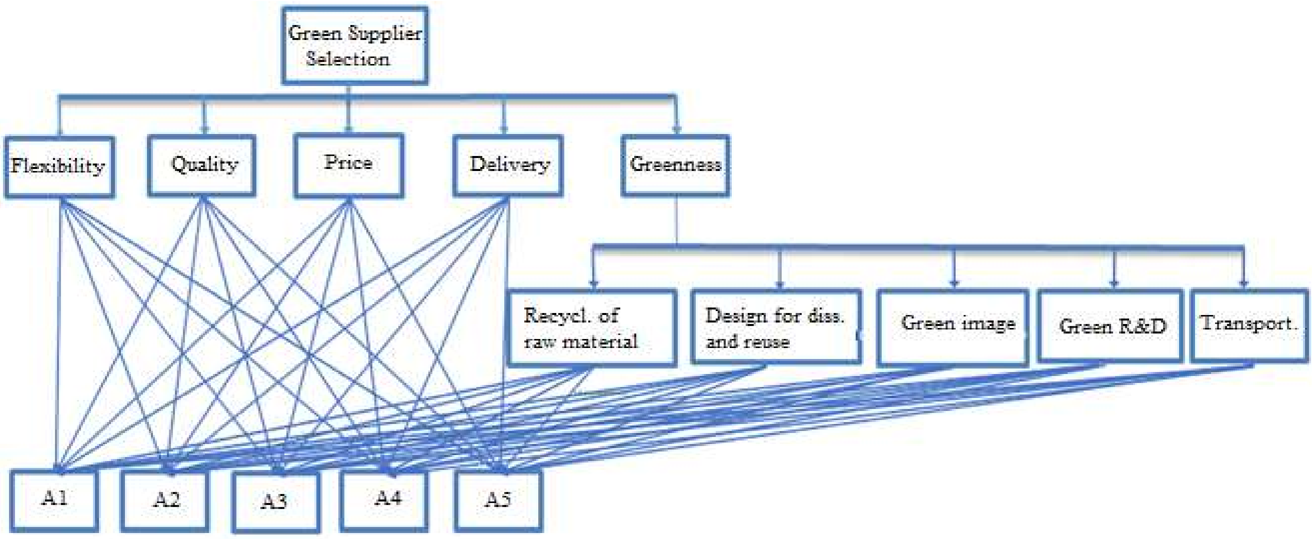

Figure 2. Hierarchical structure of main and sub criteria

shown in detail. The hierarchical diagram of the supplier selection problem is given in Figure 2. The pairwise comparison matrix between criteria mentioned in step 2 is formed by using TIFNs given in Table 1 based on the negotiation between the DMs. The pairwise comparison matrix between the main criteria is shown in Table 5. The step of weighting of DMs mentioned in Step 3 have not implemented because of the compromise between decision makers. The unified fuzzy decision matrix described in step 4 is based on the weight of the compromise evaluation between DMs. In this step, Equation (2) is utilized to unify the whole of transformation of the IF decision matrix of each factor. The results are shown in Table 6. For example, the calculation of unified matrix of greenness criterion considering compromise assessment is shown as follows:

$$= \begin{bmatrix} 1 - \prod \begin{pmatrix} (1-0.27)^1 * (1-0.27)^1 * \\ (1-0.22)^1 * \\ (1-0.02)^1 * (1-0.13)^1 \end{pmatrix} \\ \prod \begin{pmatrix} (0.33)^1 * (0.13)^1 * (0.28)^1 * \\ (0.18)^1 * (0.27)^1 \end{pmatrix} \\ \prod \begin{pmatrix} (1-0.27)^1 * (1-0.27)^1 * \\ (1-0.22)^1 * \\ (1-0.02)^1 * (1-0.13)^1 \end{pmatrix} \\ - \prod \begin{pmatrix} (0.33)^1 * (0.13)^1 * (0.28)^1 * \\ (0.18)^1 * (0.27)^1 \end{pmatrix} \end{bmatrix} = (0.65, 0.001, 0.349)$$

Computation of the CR of the unified IF decision matrix of criterion mentioned in the step 5 is performed using Equation (3).

$$= \frac{\left(\left((0+0+0.505+0.349+0.369)/5\right)/4\right)}{1.12} = 0.05$$

As seen in this computation, the CR of the unified IF decision matrix is 0.05. The matrix is stable because this value is less than 0.10. At the last step, entropy weights of every main criteria and final entropy weights are obtained by utilizing Equation (4) and (5), respectively. For instance, calculation of the entropy weight and the final entropy weight of the price as follows:

$$\bar{\bar{w}}_{price} = -\frac{1}{5\ln 2}[0.49\ln 0.49 + 0.005\ln 0.005 - (1-0.505)\ln(1-0.505) - 0.505\ln 2] = 0.1090$$

$$= \frac{1-0.1090}{5-(0+0+0.1090+0.0719+0.0759)} = 0.1878$$

The entropy weights of the quality and delivery criteria are computed as zero. The entropy weights of price, green and flexibility criteria are computed as 0.1090, 0.0719 and 0.0759, respectively. Compromise assessment has also been taken into account when comparing sub-criteria. It is shown in Table 7. The unified matrix of the sub criteria generated by the TIFNs is given in Table 8.

Table 5. Pairwise comparison of main criteria in TIFNs

Main criteria	Quality	Delivery	Price	Greenness	Flexibility
Quality	(0.02,0.18, 0.80)	(0.13,0.27, 0.60)	(1.0,0,0)	(0.33,0.27, 0.40)	(0.62,0.18, 0.20)
Delivery	(0.27, 0.13, 0.60)	(0.02,0.18, 0.80)	(1.0,0,0)	(0.13,0.27, 0.60)	(0.33,0.27, 0.40)
Price	(0,1.0,0)	(0,1.0,0)	(0.02,0.18, 0.80)	(0.28,0.22, 0.50)	(0.27, 0.13, 0.60)
Greenness	(0.27, 0.33, 0.40)	(0.27,0.13, 0.60)	(0.22,0.28, 0.50)	(0.02,0.18, 0.80)	(0.13,0.27, 0.60)
Flexibility	(0.18,0.62, 0.20)	(0.27,0.33, 0.40)	(0.13,0.27, 0,60)	(0.27, 0.13, 0.60)	(0.02,0.18, 0.80)

Table 6. Unified matrix of main criteria in TIFNs

Main criteria	Quality	Delivery	Price	Greenness	Flexibility	Unified matrix
Quality	(0.02,0.18,0.80)	(0.13,0.27, 0.60)	(1.0,0,0)	(0.33,0.27, 0.40)	(0.62,0.18, 0.20)	(1.0,0,0)
Delivery	(0.27,0.13,0.60)	(0.02,0.18, 0.80)	(1.0,0,0)	(0.13,0.27, 0.60)	(0.33,0.27, 0.40)	(1.0,0,0)
Price	(0,1.0,0)	(0,1.0,0)	(0.02,0.18, 0.80)	(0.28,0.22, 0.50)	(0.27, 0.13, 0.60)	(0.49, 0.005, 0.505)
Greenness	(0.27,0.33,0.40)	(0.27, 0.13, 0.60)	(0.22,0.28, 0.50)	(0.02,0.18, 0.80)	(0.13,0.27, 0.60)	(0.65,0.001, 0.349)
Flexibility	(0.18,0.62,0.20)	(0.27,0.33, 0.40)	(0.13,0.27, 0.60)	(0.27, 0.13, 0.60)	(0.02,0.18, 0.80)	(0.63,0.001, 0.369)

Table 7. Pairwise comparison of sub criteria in TIFNs

Sub criteria	Recycl. raw material	Design for diss. and reuse	Green image	Green R&D	Transportation
Recycl. raw material	(0.02,0.18, 0.80)	(0.13,0.27,0.60)	(1.0,0,0)	(0.62,0.18,0.20)	(0.47,0.23,0.30)
Design for diss. and reuse	(0.27,0.13,0.60)	(0.02,0.18,0.80)	(1.0,0,0)	(0.33,0.27,0.40)	(0.33,0.27,0.40)
Green image	(0,1.0,0)	(0,1.0,0)	(0.02,0.18,0.80	(0.23,0.06,0.70	(0.27,0.13,0.60)
Green R&D	(0.18,0.62,0.20)	(0.27,0.33,0.40)	(0.06,0.23,0.70)	(0.02,0.18, 0.80)	(0.27,0.33,0.40)
Transportation	(0.23,0.47,0.30)	(0.27,0.33,0.40)	(0.13,0.27,0.60)	(0.33,0.27,0.40)	(0.02,0.18,0.80)

Table 8. Unified matrix of sub criteria in TIFNs

Sub criteria	Recycl. raw material	Design for dis. and reuse	Green image	Green R&D	Transportation	Unified matrix
Recycl. Raw material.	(0.02,0.18, 0.80)	(0.13,0.27, 0.60)	(1.0,0,0)	(0.62,0.18, 0.20)	(0.47,0.23, 0.30)	(1.0,0,0)
Design for disa. and reuse.	(0.27,0.13, 0.60)	(0.02,0.18, 0.80)	(1.0,0,0)	(0.33,0.27, 0.40)	(0.33,0.27, 0.40)	(1.0,0,0)
Green image	(0,1.0,0)	(0,1.0,0)	(0.02,0.18, 0.80)	(0.23,0.06, 0.70)	(0.27,0.13, 0.60)	(0.45,0.001, 0.549)
Green R&D	(0.18,0.62, 0.20)	(0.27,0.33, 0.40)	(0.06,0.23, 0.70)	(0.02,0.18, 0.80)	(0.27,0.33, 0.40)	(0.60, 0.003, 0.397)
Transportation	(0.23,0.47, 0.40)	(0.27,0.33, 0.40)	(0.13,0.27, 0.60)	(0.33,0.27, 0.40)	(0.02,0.18, 0.80)	(0.68,0.002, 0.318)

The CR of the unified IF decision matrix for sub criteria is also calculated as 0.05. The entropy and final entropy weights of each sub criterion are similarly computed. For instance, calculation the entropy weight and the final entropy weight of the green image are as follows:

$$\bar{\bar{w}}_{g.i.} = -\frac{1}{5\ln 2}[0.45\ln 0.45 + 0.001\ln 0.001 - (1-0.549)\ln(1-0.549) - 0.549\ln 2] = 0.1118$$

$$= \frac{1-0.1118}{5-(0+0+0.1118+0.0848+0.0675)} = 0.1875$$

Final entropy weight of greenness is computed as 0.1956 in the previous step. However, at last, since the green image criterion is a sub-criterion of the greenness criterion, the final entropy weights of greenness and green image are multiplied:

$$w_{greenness} \times w_{green\ image} = 0.1956 \times 0.1875 = 0.0366$$

Final entropy weights of each main and sub criterion are demonstrated in Table 9.

4.2. PROMETHEE

The PROMETHEE method described in Section 3.2 has been used for sorting alternatives considering weights of the criteria. At first, the data matrix created by weights and alternatives assessed by the criteria is given in Table 10. As constructing the data matrix, DMs reconciled and rated alternatives by utilizing a 10-point Likert-type scale considering the criteria.

The preference functions described in step 2 are determined for each criterion. In determining the preference functions for the criteria, the structure of the criterion, the values it can take, and the views of the managers and experts on the criteria are evaluated. Hence, the fifth type preference function is determined as suitable for all the criteria. However, in the price criterion assessment, the supplier offering the lowest price is considered to receive the highest score. The preference function and the related parameters for each of the criteria are given in Table 11. Then, the preference indices for alternatives are calculated by Equation (7) considering common preference functions for the pair of alternatives. Similar calculations are made for other alternative pairs. The results obtained are shown in Table 12.

Table 9. Final entropy weights of main and sub criteria

Criteria	Entropy weights	Final entropy weights
Quality	0	0.2108
Delivery	0	0.2108
Price	0.1090	0.1878
Flexibility	0.0759	0.1948
Recycl. of raw material	0	0.0413
Design for dis. and reuse	0	0.0413
Green image	0.1118	0.0366
Green R&D	0.0848	0.0378
Transportation	0.0675	0.0386

Table 10. Data matrix

Alter.	Criteria								
	Quality (Max)	Delivery (Max)	Price (Max)	Flex. (Max)	Recycl. of raw mat. (Max)	Design for diss. & reuse (Max)	Green image (Max)	Green R&D (Max)	Trans. (Max)
A	3	2	4	7	5	4	7	4	5
B	6	8	6	5	9	7	9	3	6
C	3	6	9	6	6	8	5	2	4
D	9	4	5	5	5	5	4	2	3
E	5	9	4	8	7	6	2	5	8
Weights	0.2108	0.2108	0.1878	0.1948	0.0413	0.0413	0.0366	0.0378	0.0386

Table 11: Determined preference functions and parameters for each criterion

Criteria	Parameter	Function
Quality (max)	2, 4	$p_{quality} = \begin{cases} 0, \mathrm{x} \le 2 \\ \frac{x-2}{2}, 2 < x \le 4 \\ 1, x > 4 \end{cases}$
Delivery (max)	3, 5	$p_{delivery} = \begin{cases} 0, \mathrm{x} \le 3 \\ \frac{x-3}{2}, 3 < x \le 5 \\ 1, x > 5 \end{cases}$
Price (max)	2, 4	$p_{price} = \begin{cases} 0, \mathrm{x} \le 2 \\ \frac{x-2}{2}, 2 < x \le 4 \\ 1, x > 4 \end{cases}$
Flexibility (max)	1, 3	$p_{flexibility} = \begin{cases} 0, \mathrm{x} \le 1 \\ \frac{x-1}{2}, 1 < x \le 3 \\ 1, x > 3 \end{cases}$
Recyclability of raw material (max)	3, 5	$p_{recycl.} = \begin{cases} 0, \mathrm{x} \le 3 \\ \frac{x-3}{2}, 3 < x \le 5 \\ 1, x > 5 \end{cases}$
Design for disassembly and reuse (max)	2, 4	$p_{designfordis.} = \begin{cases} 0, \mathrm{x} \le 2 \\ \frac{x-2}{2}, 2 < x \le 4 \\ 1, x > 4 \end{cases}$
Green image (max)	3, 5	$p_{greenimage} = \begin{cases} 0, \mathrm{x} \le 3 \\ \frac{x-3}{2}, 3 < x \le 5 \\ 1, x > 5 \end{cases}$
Green R&D (max)	1,3	$p_{greenR\&D} = \begin{cases} 0, x \le 1 \\ \frac{x-1}{2}, 1 < x \le 3 \\ 1, x > 3 \end{cases}$
Transportation (max)	2, 4	$p_{transportation} = \begin{cases} 0, \mathrm{x} \le 2 \\ \frac{x-2}{2}, 2 < x \le 4 \\ 1, x > 4 \end{cases}$

Table 12. Calculated preference indices for alternative suppliers

	A	B	C	D	E
A	-	0.0974	0.0189	0.1163	0.0366
B	0.3575	-	0.1237	0.1819	0.0366
C	0.3345	0.0939	-	0.2084	0.1878
D	0.2108	0.1054	0.2108	-	0.2108
E	0.2301	0.2137	0.1738	0.4820	-

Table 13. Positive and negative priorities for alternative suppliers

Alternative	A	B	C	D	E
Φ^{+}	0.2692	0.6997	0.8246	0.7378	1.0996
Φ^{-}	1.1329	0.5104	0.5272	0.9886	0.4718

In the next step, positive and negative priorities are calculated for the alternative suppliers by Equations (8) and (9), respectively. Calculation of positive and negative priorities for Alternative A is shown below as an example and the results for the other alternatives are shown in Table 13.

$$\Phi^{+}(A) = \pi(A,B) + \pi(A,C) + \pi(A,D) + \pi(A,E)$$

=0.0974+0.0189+0.1163+0.0366=0.2692

$$\Phi^{-}(A) = \pi(B,A) + \pi(C,A) + \pi(D,A) + \pi(E,A)$$

=0.3575+0.3345+0.2108+0.2301=1.1329

Finally, the complete ranking is determined by PROMETHEE II method. The complete priorities of the alternatives are calculated by Equation (10). Equations (11) and (12). The complete ranking is shown in Figure 3. As a result of ranking, supplier E has been identified as the most suitable green supplier for the company. Other suppliers are listed as C-B-D-A respectively.

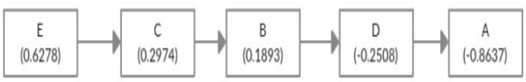

Figure 3. Complete ranking of suppliers

5. CONCLUSION

This paper proposed an integrated model for green supplier selection. IF-AHP is considered as an appropriate method to weigh the criteria since it is easy and robust to implement in spite of the ambiguity of human decision in the assessment period. At first, IF-AHP is applied to determine the criteria weights. Afterwards, PROMETHEE which is regarded as a proper and practical outranking method, is applied to rank the alternative suppliers considering the criteria weights. Eventually, an application is presented for the validation and detailed analysis of the proposed method.

The contribution of this research can be grouped under four headings. First, IF-AHP method which emerges recently in the literature and is powerful enough to remove the ambiguity in decision-making problems is used. The second contribution is to avoid time wasting by providing a consensus assessment between decision makers. The third contribution is that the criterion weight values are obtained without defuzzification operation by the proposed IF-AHP method. The final contribution is that the proposed approach is applied for the first time in the filter industry. Thus, managers and company owners who desire to make green supplier selection in the filter industry can benefit from this study. Green and classical criteria used in this study can also be used in the selection of suppliers in some other sectors such as automotive, electronics or textile. However, the criteria such as recyclability of raw material design for disassembly and reuse are not suitable for the selection of green suppliers in the service sector.

Although this paper is a comprehensive study, green supplier selection is an appropriate area for development. In order to overcome the uncertainty of the problem in future studies, it can be used to compare the criteria by integrating the intuitionistic fuzzy logic with the Analytical Network Process method which evaluates the feedback between intergroup and intergroup dependencies and criteria. However, Intuitionistic Fuzzy PROMETHEE can be applied to avoid uncertainties in the order of suppliers. Finally, another superiority method, ELECTRE, can be used to rank suppliers and the results can be compared to the results suggested in this study.

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