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INTEGRATED FAHP, ARAS-F AND MSGP METHODS FOR GREEN SUPPLIER EVALUATION AND SELECTION

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Abstract. In recent years, determining the best supplier in the green supply chain has become a key strategic task for a firm. Since the decision usually involves several objectives or criteria, the green supplier selection process is a fuzzy multiple criteria decision-making (FMCDM) problem. Considering both qualitative and quantitative criteria, this study proposes new integrated fuzzy techniques for fuzzy analytic hierarchy process (FAHP), fuzzy additive ratio assessment (ARAS-F) and multi-segment goal programming (MSGP) approach to solve the green supplier selection problems. The advantage of this method is that it allows decision makers to set multiple segment aspiration levels for green supplier selection problems. The integrated model is illustrated by an example in a watch firm.

Keywords: fuzzy analytic hierarchy process (FAHP), fuzzy additive ratio assessment (ARAS-F), multi-segment goal programming (MSGP), green supplier selection, decision-making.

JEL Classification: C02, C61, L68, M11, M31.

Introduction

Today's international business environment has required many firms to focus on green supply chain management to gain a competitive advantage. During recent years, green supplier selection process in the green supply chain has become a key strategic consideration (Shenc *et al.* 2013). In order to obtain the greatest benefits from environmental management, businesses must integrate all members in the green supply chain (GSC) (Lee *et al.* 2009). Therefore, "green supply" principles and strategies have become key success factors for business as the public awareness increased against their environmental impacts. A firm's environmental performance is not only related to the business's inner environmen-

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tal efforts, but also it is affected by the suppliers' environmental performance and image (Büuyüközkan, Cifci 2012).

The main purpose of green supply chain management (GSCM) process is to decrease environmental pollution and hazardous materials from the green supplier during purchasing, manufacturing, marketing and obsolescing of products. Hazardous substances provided by suppliers may cause serious environmental impact in the supply chain. Due to governmental legislation and increased focus on environmental protection strengthened by the awareness of people, businesses cannot ignore environmental issues if they want to maintain their competitive advantage in the area of green lifestyle. Growing environmental concerns means it is necessary to consider environmental pollution issues that accompany economical development in supply chain management activities, leading to the emerging concept of GSCM (Hsu, Hu 2009; Diabat, Kannan 2011; Kannan *et al.* 2013).

Multi-criteria decision making (MCDM) method is a decision-making analysis method, which has been applied for selection problems (Wu *et al.* 2012). Green supplier selection is a MCDM problems containing both qualitative criteria (e.g., service quality and environment skill, etc.) and quantitative criteria (e.g., benefit and cost, etc.) are in conflict in business resource. For any manufacturing, selecting the right upstream green suppliers is a key success factor that will significantly reduce environmental cost, increase downstream customer satisfaction, and improve competitive ability. Therefore, choosing suitable green suppliers becomes a crucial issue. Over the last few years, a number of techniques have been proposed to solve the green supplier selection problems, which can deal with the problem effectively (Kannan *et al.* 2013). For example, analytic hierarchy process (AHP), fuzzy AHP (FAHP), analytic network process (ANP), interpretive structural modelling (ISM), case-based reasoning (CBR), data envelopment analysis (DEA), genetic algorithm (GA), neural networks (NN), Taguchi loss function, techniques for order preference by similarity to ideal solution (TOPSIS), and analytic hierarchy process fuzzy TOPSIS. In multiple choice or segment goals, many researchers have applied different methods of mathematical programming such as linear programming (LP), goal programming (GP), mixed integer GP and multi-choice goal programming (MCGP) in supplier selection problems.

In this study, a new integrated method combining FAHP, fuzzy additive ratio assessment (ARAS-F) and Multi-segment goal programming (MSGP) is proposed to solve the FMCDM problem of green supplier selection. First, FAHP is used to calculate the relative weight of each criterion based on the subjective judgments of decision-making group from the example company. Second, the ARAS-F method was used to obtain a closeness coefficient for the performance of each alternative green supplier with respect to each criterion. In the final step, quantitative constraints, such as those related to cost and benefit criteria, are incorporated into the MSGP model to identify the optimal green supplier. The method and steps of this integration are shown in Figure 1.

The rest of this study is organized as follows. Section 1 reviews the criteria for green supplier selection. Section 2 introduces FAHP, ARAS-F and MSGP methodology. Section 3 applies the integrated method to the green supplier selection problem with a numerical example. Finally, the last Section provides the conclusion and suggestion for future research.

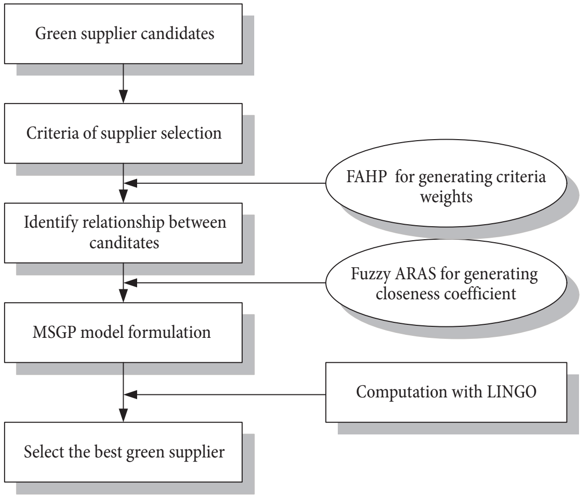

Fig. 1. The integration procedure

1. The criteria for green supplier's selection

Supplier selection in GSCM has been identified as significant in making purchasing decisions (Seuring, Muller 2008). In practice, GSCM has focused on encouraging existing suppliers to improve their environmental performance. The past few years have many researchers to investigate the environmental concepts in green supplier evaluation and selection. Chen *et al.* (2006) addressed supplier selection problem in green supply chain using five benefit criteria including the technological capability, conformance quality, profitability of supplier, relationship closeness, and conflict resolution. Lin and Chang (2008) claimed that business position, communication, reputation, customer responsiveness, relationship closeness, and conflict solving capabilities are all important criteria for supplier selection. Lee *et al.* (2009) presented a green supplier selection problems by using quality, technology capability, pollution control, environment management skill, green products and green competencies. Wang *et al.* (2009) address the role of organizational size in the green supplier selection process. Hsu and Hu (2009) proposed supplier selection criteria consideration to hazardous substance management including green materials coding and recording, green purchasing, green design capability, hazardous substances inventory and management, legal-compliance competency, and environmental management skill. Önüt *et al.* (2009) proposed that green supplier selection involves six criteria, price, delivery lead time, institutionally quality and execution time. Guneri *et al.* (2009) suggested that performance history, conflict solving capability relationship closeness, business reputation and delivery time are key criteria for supplier evaluation. In addition, Bai and Sarkis (2010) summarized green environmental factors such as pollution controls, pollution prevention, environmental management skill, resource consumption, and pollution production into green supplier selection. Liao and Kao (2010) suggested that the supplier selection process, firms must consider whether product quality, purchase cost, delivery time, and service quality to meet customer's demand. Awasthi *et al.* (2010) presented a fuzzy multiple criteria for evaluating suppliers' environmental performance and mentioned that availability of clean materials, environmental efficiency and costs, green image and products, environmental and legislative management, and green process management. Kuo *et al.* (2010) integrated artificial neural network (ANN), DEA and ANP for green supplier selection and using quality, cost, delivery, service, environment skill, and corporate social responsibility criteria. Lin *et al.* (2011) claimed that price, quality, service satisfaction, trust, and delivery are key criteria for supplier evaluation in green supplier chain management.

For green supplier selection, Yeh and Chuang (2011) developed two multiple objective genetic algorithms which involved four objectives such as cost, product quality, time, and green evaluation score. In addition, Büuyüközkan and Cifci (2012) summarized five major criteria including organization, service quality, financial performance, technology, and green competencies for green suppliers' evaluation and selection. Organization factor shows the supplier's degree of cooperation relationship closeness and attitudes are the critical factors for the supplier to be appropriate to green supply chain. Service quality contains the factors that can improve the quality of information, time delivery capability and time response to request. Financial performance shows the control of the supplier economically. For example, financial position, economical stability and price or cost can fit the financial performance. Technology is the other factor such as skill of R&D, green technology and green product design capability for green suppliers' evaluation and selection. Finally, green competencies show the competencies of supplier in social responsibility, cleaner production and technologies environmental management system.

Recently, Kannan *et al.* (2013) applied fuzzy analytic hierarchy process and fuzzy technique for order preference by similarity to ideal solution to determine the best green suppliers. They offer cost, quality, delivery, technology capability and environmental competency criteria for green supplier selection. Govindan *et al.* (2013) proposed a fuzzy multiple criteria method for measuring a sustainability green supplier and considered pollution production, resource consumption, eco-design and environmental management system. Moreover, Shenc *et al.* (2013) proposed a fuzzy multiple criteria method consideration green product design issues and suppliers' environmental management performance to select green suppliers in GSCM. The evaluation criteria including pollution production, resource consumption, eco-design, green image, environmental management system, commitment of GSCM from managers, use of environmentally friendly technology, use of environmentally friendly materials, and staff in environmental training.

In addition, many researchers have proposed various types of green suppliers' selection including Kannan *et al.* (2009); Amin *et al.* (2011); Jolai *et al.* (2011); Liao and Kao (2010, 2011), and Amin and Zhang (2012). These researchers have summarized the most important criteria such as quality, cost, price, and delivery performance in green suppliers' selection problems.

2. The proposed method

2.1. Fuzzy analytical hierarchy process (FAHP)

FAHP is a technology for solving fuzzy MCDM (FMCDM) in management problems. The basic goal of FMCDM is to decide the best choice from a fuzzy set of competing alternatives that are evaluated under conflicting criteria (Liao 2013a). Its primary characteristic is that it is based on pairwise comparison DMs' judgments. To determine the relative importance of distinct criteria in decision-making problems involves a high degree of individual preference and subjective judgment from DMs (Liao, Kao 2014). However, the linguistic measurement of human judgments is usually vague; it is to give interval value judgments rather than fixed value judgments. Hence, pairwise comparison under classic AHP may not be suitable to select set arbitrary values in decision-making process. FAHP theory has proven advantages in uncertain, imprecise and vague situation as well as in its use of approximate information to handle imprecise decision-making problems (Liao 2011).

Here a brief introduction of the fuzzy set theory is presented. A fuzzy set is characterized by a membership function, which assigns to each member of the set a grade of membership ranging from zero to one. In fuzzy set, general terms, such as "large", "medium", and "small", will be used to capture a range of numerical values. The most typical fuzzy set membership function is triangular membership function (see Fig. 2) Fuzzy triangular numbers are popular in fuzzy applications. The procedure of FAHP involves steps that can be found in Saaty (Saaty 2000; Fu *et al.* 2008).

A fuzzy number A is described as a fuzzy subset of the real line X with a member function, u_A, which represents uncertainty. This membership function is defined in a universe of discourse of [0, 1]. Thus, a fuzzy triangular number (Fig. 2) can be defined as a triplet (a,b,c), where $a \le b \le c$; the membership function of the fuzzy number A can be expressed as follows (Liao 2013b):

$$u_A(x) = \begin{cases} (x-a)/(b-a), & x \in [a,b], \\ (c-x)/(c-b), & x \in [b,c], \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

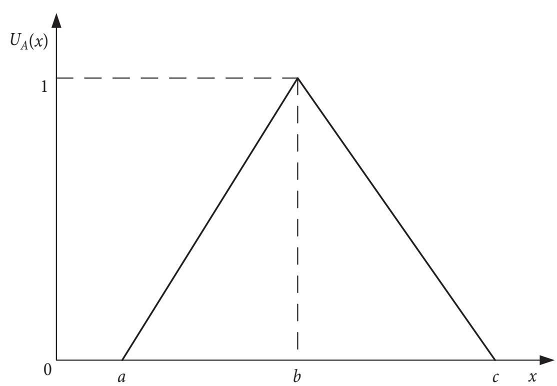

Fig. 2. Triangular membership function

Eq. (1) representation is useful for algebraic operations on fuzzy numbers. Let $\tilde{a}=(a_1,b_2,c_3)$ and $\tilde{b}=(a_1,b_2,c_3)$ be two fuzzy triangular numbers. Then, the basic operations of fuzzy triangular numbers $\tilde{a}$ and $\tilde{b}$ are defined as follows:

$$\tilde{a}\oplus\tilde{b}=(a_1+a_2,b_1+b_2,c_1+c_2); \tag{2}$$

$$\tilde{a}\Theta\tilde{b}=(a_1-c_2,b_1-b_2,c_1-a_2); \tag{3}$$

$$\tilde{a}\otimes\tilde{b}=(a_1\times a_2,b_1\times b_2,c_1\times c_2); \tag{4}$$

$$\tilde{a}(\div)\tilde{b}=(a_1\div c_2,b_1\div b_2,c_1\div a_2); \tag{5}$$

$$k\otimes\tilde{a}=(ka_1,kb_1,kc_1); \tag{6}$$

$$(\tilde{a})^{-1}=\left(\frac{1}{c_1},\frac{1}{b_1},\frac{1}{a_1}\right). \tag{7}$$

Following the logic of Chen *et al.* (2006) and Liao (2013a) for solving a FAHP problem, this study uses geometric means to defuzzy the fuzzy numbers. Assume that a decision group has K DMs and that the fuzzy ratings of all DMs preferences are the triangular fuzzy member; $\tilde{R}_k=(a_k,b_k,c_k)$. Then, the aggregated fuzzy rating can be defined as:

$$\tilde{R}=(a,b,c), \tag{8}$$

where

$$a=\min_k a_k,\ b=\sqrt[K]{\prod_{k=1}^{K} b_k}\ \text{and}\ c=\max_k c_k;\ k=1,2,\ldots,K. \tag{9}$$

Let the fuzzy rating and importance weight of the kth ($k=1,2,\cdots,K$) DMs be $\tilde{x}_{ijk}=(a_{ijk},b_{ijk},c_{ijk})$ and $\tilde{w}_{jk}=(\tilde{w}_{jk1},\tilde{w}_{jk2},\tilde{w}_{jk3})$ where $i=1,2,\cdots,m$ and $j=1,2,3,\ldots,n$. Thus, the fuzzy group ratings $\tilde{x}_{ij}$ of ith alternatives with respect to jth criterion can be calculated as (Liao 2013b):

$$\tilde{x}_{ij}=(a_{ij},b_{ij},c_{ij}), \tag{10}$$

where

$$a_{ij}=\min_k a_{ijk},\ b_{ij}=\sqrt[K]{\prod_{k=1}^{K} b_{ijk}}\ \text{and}\ c_{ij}=\max_k c_{ijk} \tag{11}$$

and the fuzzy group weights $\tilde{w}_j$ of each criterion can be calculated as (Chen *et al.* 2006; Liao 2013a):

$$\tilde{w}_j=(w_{j1},w_{j2},w_{j3}), \tag{12}$$

where

$$w_{j1}=\min_k w_{jk1},\ w_{i2}=\sqrt[K]{\prod_{k=1}^{K} w_{jk2}}\ \text{and}\ w_{j3}=\max_k w_{jk3}. \tag{13}$$

2.2. Fuzzy additive ratio assessment (ARAS-F)

A new fuzzy additive ratio assessment (ARAS-F) method was proposed by Turskis and Zavadskas (2010), and it can be classified as a newly formed, but effective and easy to use, FMCDM method. The procedure of solving problems by using ARAS-F methods can be precisely described as following steps (Zavadskas *et al.* 2010; Keršulienė, Turskis 2011; Stanujkic, Jovanovic 2012; Baležentis *et al.* 2012):

Step 1. Determine fuzzy decision-making matrix forming for each criterion.

A typical fuzzy multiple criteria decision making (FMCDM) problem, which contains *m* alternatives and *n* criteria, can be concisely expressed in a fuzzy decision-making matrix form, as follows:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{01} & \cdots & \tilde{x}_{0j} & \cdots & \tilde{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{i1} & \cdots & \tilde{x}_{ij} & \cdots & \tilde{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mj} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \quad (14)$$

where m are number of alternatives; n are number of criteria describing each alternative and $\tilde{x}_{ij}$ denote a fuzzy value representing the performance value of the i alternative in terms of the j criterion. In addition, $i = 0,1,\cdots,m$ and $j = 1,2,\cdots,n$.

If decision makers do not have preferences, the optimal performance ratings are calculated as:

$$x_{0j} = \max_i x_{ij}, \; j \in \Omega_{\max}, \quad (15)$$

and

$$x_{0j} = \min_i x_{ij}, \; j \in \Omega_{\min}, \quad (16)$$

where x_{0j} is optimal performance rating in relation to the jth criterion, denote a set of benefit type criteria; such as optimization direction is maximization; and denote a set of cost type criteria; such as optimization direction is minimization.

Step 2. Calculate the fuzzy normalized decision matrix for the initial value.

The initial values of all the criteria are normalized, i.e. defining values $\tilde{\bar{x}}_{ij}$ of normalized decision-making matrix $\tilde{\bar{X}}$ as follows:

$$\tilde{\bar{X}} = \begin{bmatrix} \tilde{\bar{x}}_{01} & \cdots & \tilde{\bar{x}}_{0j} & \cdots & \tilde{\bar{x}}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\bar{x}}_{i1} & \cdots & \tilde{\bar{x}}_{ij} & \cdots & \tilde{\bar{x}}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\bar{x}}_{m1} & \cdots & \tilde{\bar{x}}_{mj} & \cdots & \tilde{\bar{x}}_{mn} \end{bmatrix}, \quad (17)$$

$$i = 0,1,\cdots,m, \; j = 1,2,\cdots,n.$$

If the criteria are benefit type criteria, then the normalized as follows:

$$\tilde{\bar{x}}_{ij} = \frac{\tilde{x}_{ij}}{\sum_{i=0}^{m} \tilde{x}_{ij}}, \; j \in \Omega_{\max}, \quad (18)$$

and the criteria are cost type criteria, then the normalized as follows:

$$\tilde{\bar{x}}_{ij} = \frac{1/\tilde{x}_{ij}}{\sum_{i=0}^{m} 1/\tilde{x}_{ij}}, \; j \in \Omega_{\min}. \quad (19)$$

Step 3. Calculate the fuzzy normalized weighted decision matrix.

$$\tilde{\hat{X}} = \begin{bmatrix} \tilde{\hat{x}}_{01} & \cdots & \tilde{\hat{x}}_{0j} & \cdots & \tilde{\hat{x}}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\hat{x}}_{i1} & \cdots & \tilde{\hat{x}}_{ij} & \cdots & \tilde{\hat{x}}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{\hat{x}}_{m1} & \cdots & \tilde{\hat{x}}_{mj} & \cdots & \tilde{\hat{x}}_{mn} \end{bmatrix}, \quad (20)$$

$$i = 0,1,\cdots,m, \; j = 1,2,\cdots,n,$$

where the fuzzy normalized weighted values of the criteria are calculated as follows:

$$\tilde{\hat{x}}_{ij} = \tilde{\bar{x}}_{ij} \otimes \tilde{w}_j, \; i = 0,1,\cdots,m, \; j = 1,2,\cdots,n, \quad (21)$$

where $\tilde{\hat{x}}_{ij}$ is weighted normalized performance rating of ith alternative in relation to the jth criterion.

Step 4. Calculate the overall performance index for each alternative.

The overall performance index $\tilde{P}_i$, for each alternative, can be calculated as the sum of weighted normalized performance ratings, using the following equation:

$$\tilde{P}_i = \sum_{j=1}^{n} \tilde{\hat{x}}_{ij}, \; i = 0,1,\cdots,m, \quad (22)$$

where $\tilde{P}_i$ is the value of optimality function of ith alternative and the center of area is the most practical and simple to apply to:

$$P_i = \frac{1}{3}(\tilde{P}_{i\alpha} + \tilde{P}_{i\beta} + \tilde{P}_{i\gamma}), \; i = 0,1,\cdots,m. \quad (23)$$

Step 5. Calculate the degree of utility for each alternative.

The degree of the alternative utility is determined by a comparison of variant, which is analyzed, with the most ideal one P_0. The utility degree of an alternative A_i, can be calculated using the following equation:

$$Q_i = \frac{P_i}{P_0}, \; i = 0,1,\cdots,m, \quad (24)$$

where P_0 and P_i are obtained from Eq. (23), and Q_i is degree of utility of ith alternative and its calculated values are in the interval [0, 1]. The largest value of Q_i is the best and the smallest one is the worst.

Step 6. Rank alternatives and select the most efficient one.

The considered alternatives are ranked by ascending Q_i, therefore, determination of the most appropriate alternative, A_i^*, can be done with the following equation:

$$A_i^* = \left\{ A_i \middle| \max_i Q_i \right\}, \; i = 1,2,\cdots,m. \quad (25)$$

2.3. Multi-segment goal programming (MSGP)

GP is one of the most powerful techniques of multiple objective optimizations and has been applied to solve various decision-making problems. GP is a multiple objective analytical approach devised to address management and economics problems. Where targets have been assigned to all attributes and where the decision makers are interested in minimizing the non-achievement of the corresponding goal (Liao 2013b). Liao (2009) proposed a MSGP approach to solve multiple segment aspiration levels (MSAL) problems in which DMs can set multiple aspiration levels to each segment goal level and the achievement function of MSGP can be done with the follows equations:

$$\text{Min } Z = \sum_{i=1}^{n} w_i (d_i^+ + d_i^-) \tag{26}$$

$$\text{s.t. } f_i(x) + d_i^+ - d_i^- = g_i, \; i = 1,2,\ldots n, \tag{27}$$

$$f_i(x) = \sum_{j=1}^{m} s_{ij} B_{ij}(b) \cdot x_i; \tag{28}$$

$$s_{ij} B_{ij}(b) \in R_i(x), \;\; i = 1,2,\ldots n, \;\; j = 1,2,\ldots.,m, \tag{29}$$

$$d_i^+, \, d_i^- \geq 0, \;\; i = 1,2,\ldots n, \;\; X \in F \;\; (F \text{ is a feasible set}),$$

where w_i represents the weight attached to the deviation and d_i is the deviation from the target value g_i. The $d_i^+ = \max\ (0, f_i(x) - g_i)$ and $d_i^- = \max\ (0, g_i - f_i(x))$, represent under- and over-achievements of the *i*th goal, respectively. The s_{ij} is a decision variable coefficient that represents the multiple segment aspiration levels of *j*th segment of *i*th goal. In addition, $B_{ij}(b)$ represents a function of a binary serial number and $R_i(x)$ is the function of resource limitations.

Follow the Chang (2007) concept, the MSGP model can be rewrite as following MSGP achievement type:

$$\text{Min } S = w_i((d_i^+ + d_i^-) + (e_i^+ + e_i^-)) \tag{30}$$

$$\text{s.t. } \sum_{j=1}^{m} s_{ij} B_{ij}(b) \cdot x_i + d_i^+ - d_i^- = g_i; \tag{31}$$

$$1/L_i \, (b_i s_{ij}^{\max} + (1 - b_i)\, s_{ij}^{\min}) - e_i^+ + e_i^- = 1 + i/L_i \, (s_{ij}^{\max} \text{ or } s_{ij}^{\min}), \; L_i = s_{ij}^{\max} - s_{ij}^{\min}; \tag{32}$$

$$s_{ij} B_{ij}(b) \in R_i(x), \tag{33}$$

$$b_i \in \{0,1\}, \; d_i^+, d_i^-, e_i^+, e_i^- \geq 0, \; X \in F \;\; (F \text{ is a feasible set}),$$

where $i = 1,2,\ldots n$ and $j = 1,2,\ldots.,m$; all other variables are defined as in the MSGP model.

3. A numerical example

To consider business strategy and culture, the example company of watch manufacture, Formosa Co., Ltd. (FCL) seeks the best green supplier for advance green product performance and reputation improvement. The chief executive officer (CEO) desires to determine the optimal green supplier. FCL's decision-making group consisted of three members: the CEO, the chief marketing manager, and the chief purchase officer. In addition, two environmental experts were invited to participate in this group and provide their opinions.

The decision-making group including CEO (D_1), the chief marketing manager (D_2), the chief purchase officer (D_3), green supplier (D_4) and environmental management experts (D_5), they have rich experience in green supplier evaluation problems. The decision-making group from five qualified suppliers (S_1, S_2, S_3, S_4, S_5) by applying the Delphi technique (see Hsu *et al.* 2011; Rowe, Wright 2011; Worrell *et al.* 2013) to select a best green supplier. In addition, base on the literature reviews, data analysis and using Nominal Group Technique (NGT) (see Appendix) the five qualitative criteria for selecting the best green supplier are purchase cost (C_1), quality service (C_2), technology capability (C_3), environment skill (C_4) and delivery performance (C_5) for the present case. The definition of criteria is presented in Table 1.

Table 1. The supplier selection criteria definition

Criteria	Definition
C_1: Purchase cost	The purchase cost that determines the product price includes material cost, logistics cost, quantity discount, maintenance cost, and warranty cost etc.
C_2: Quality service	To obtain quality assurance such as certificates and rejection ratio number (e.g., rejected incoming material detected by quality control).
C_3: Technology capability	Technology development (e.g., green technology level, skill of R&D, capability of green product design etc.) of the supplier to meet current and future demand of the firm.
C_4: Environment skill	Design of products for reduced pollution production, and reduced resource consumption of raw material, energy and water, green design of products for reuse, recycle, recovery of material.
C_5: Delivery performance	Can reduced the time between production and arrival of an order, promise of order quantities etc.

Source: Lee *et al.* 2009; Bai, Sarkis 2010; Awasthi *et al.* 2010; Yeh, Chuang 2011; Büuyüközkan, Cifci 2012; Kuo *et al.* 2010; Govindan *et al.* 2013; Kannan *et al.* 2013.

Five green suppliers (S_1, S_2, S_3, S_4, and S_5) remain for further evaluation and selection. The purchase cost is the cost criterion, and all other identified criteria (as outlined above) are benefit criteria. The linguistic variables for the importance weight of each criterion are shown in Table 2, and the fuzzy preferences that are used in the study are shown in Table 3. The hierarchical structure of this decision problem is presented in Figure 3.

Step 1. The five DMs use the linguistic weighting variables shown in Table 2 to assess the importance of the criteria. The importance fuzzy weights of the criteria determined by the five DMs are shown in Table 4.

Step 2. The five DMs use the linguistic rating variables shown in Table 3 to evaluate the rating of each candidate with respect to each criterion and then present the ratings in Table 5.

Step 3. The weights of each criterion (w_i) in Table 4 and the linguistic evaluations in Table 5 are used to create a fuzzy weighted decision matrix. Table 6 shows the fuzzy weighted decision values.

Table 2. Linguistic variables for the importance weight of each criterion

Linguistic variables	Triangular fuzzy number
Very low	(0, 0, 0.2)
Low	(0, 0.2, 0.4)
Fairly low	(0.2, 0.4, 0.6)
Fairly high	(0.4, 0.6, 0.8)
High	(0.6, 0.8, 1)
Very high	(0.8, 1, 1)

Table 3. Fuzzy preference used in this stud.

Linguistic terms	Fuzzy preference
Very low	(0, 0, 2)
Low	(0, 2, 4)
Fairly low	(2, 4, 6)
Fairly high	(4, 6, 8)
High	(6, 8, 10)
Very high	(8, 10, 10)

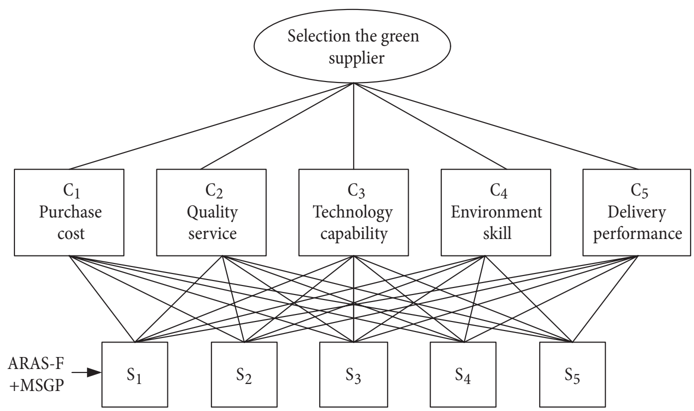

Fig. 3. Hierarchy structure of green supplier selection

Table 4. Importance fuzzy weight of criteria from five DMs

	D_1	D_2	D_3	D_4	D_5	$\tilde{w}_i$
C_1	(0.4,0.6,0.8)	(0.2,0.4,0.6)	(0.4,0.6,0.8)	(0.6,0.8,1)	(0.6,0.8,1)	(0.2,0.62,1)
C_2	(0.2,0.4,0.6)	(0.4,0.6,0.8)	(0.4,0.6,0.8)	(0.4,0.6,0.8)	(0.4,0.6,0.8)	(0.4,0.55,0.8)
C_3	(0.6,0.8,1)	(0.6,0.8,1)	(0.6,0.8,1)	(0.4,0.6,0.8)	(0.6,0.8,1)	(0.4,0.76,1)
C_4	(0.4,0.6,0.8)	(0.2,0.4,0.6)	(0.4,0.6,0.8)	(0.2,0.4,0.6)	(0.4,0.6,0.8)	(0.2,0.51,0.8)
C_5	(0.4,0.6,0.8)	(0.4,0.6,0.8)	(0.8,1,1)	(0.4,0.6,0.8)	(0.4,0.6,0.8)	(0.2,0.66,1)

Table 5. Fuzzy preferences for the five criteria by DMs

		S_1	S_2	S_3	S_4	S_5
C_1	D_1	(4,6,8)	(6,8,10)	(2,4,6)	(4,6,8)	(2,4,6)
	D_2	(4,6,8)	(2,4,6)	(6,8,10)	(4,6,8)	(2,4,6)
	D_3	(2,4,6)	(2,4,6)	(2,4,6)	(2,4,6)	(2,4,6)
	D_4	(2,4,6)	(4,6,8)	(2,4,6)	(2,4,6)	(4,6,8)
	D_5	(2,4,6)	(2,4,6)	(4,6,8)	(2,4,6)	(8,10,10)

End of Table 5

		S_1	S_2	S_3	S_4	S_5
C_2	D_1	(2,4,6)	(2,4,6)	(6,8,10)	(6,8,10)	(4,6,8)
	D_2	(0,4,6)	(4,6,8)	(8,10,10)	(8,10,10)	(2,4,6)
	D_3	(4,6,8)	(2,4,6)	(2,4,6)	(6,8,10)	(4,6,8)
	D_4	(4,6,8)	(0,2,4)	(6,8,10)	(8,10,10)	(4,6,8)
	D_5	(4,6,8)	(4,6,8)	(4,6,8)	(4,6,8)	(2,4,6)
C_3	D_1	(6,8,10)	(2,4,6)	(2,4,6)	(4,6,8)	(2,4,6)
	D_2	(4,6,8)	(4,6,8)	(4,6,8)	(8,10,10)	(4,6,8)
	D_3	(2,4,6)	(2,4,6)	(4,6,8)	(4,6,8)	(4,6,8)
	D_4	(4,6,8)	(2,4,6)	(2,4,6)	(6,8,10)	(0,2,4)
	D_5	(4,6,8)	(6,8,10)	(4,6,8)	(2,4,6)	(4,6,8)
C_4	D_1	(4,6,8)	(2,4,6)	(2,4,6)	(4,6,8)	(2,4,6)
	D_2	(2,4,6)	(2,4,6)	(4,6,8)	(2,4,6)	(4,6,8)
	D_3	(4,6,8)	(4,6,8)	(2,4,6)	(4,6,8)	(2,4,6)
	D_4	(2,4,6)	(2,4,6)	(2,4,6)	(8,10,10)	(8,10,10)
	D_5	(4,6,8)	(2,4,6)	(4,6,8)	(8,10,10)	(2,4,6)
C_5	D_1	(4,6,8)	(2,4,6)	(8,10,10,)	(2,4,6)	(4,6,8)
	D_2	(6,8,10)	(4,6,8)	(0,2,4)	(4,6,8)	(4,6,8)
	D_3	(6,8,10)	(2,4,6)	(4,6,8)	(2,4,6)	(8,10,10)
	D_4	(4,6,8)	(4,6,8)	(6,8,10)	(4,6,8)	(4,6,8)
	D_5	(6,8,10)	(2,4,6)	(4,6,8)	(4,6,8)	(6,8,10)

Table 6. The fuzzy decision matrix of five alternatives

	S_1	S_2	S_3	S_4	S_5
C_1	(2,4.70,8)	(2,4.98,10)	(2,4.98,10)	(2,4.70,8)	(2,5.21,10)
C_2	(0,4.44,10)	(0,4.10,8)	(2,6.88,10)	(6,8.26,10)	(2,5.10,8)
C_3	(2,5.86,8)	(2,4.98,10)	(2,5.10,8)	(2,6.88,10)	(0,4.44,8)
C_4	(2,5.10,8)	(2,4.34,8)	(2,4.70,8)	(2,6.79,10)	(2,5.21,10)
C_5	(4,7.13,10)	(4,4.70,8)	(0,5.65,10)	(2,5.10,8)	(4,7.04,10)

Step 4. Using Eqs (14)–(17) that the change fuzzy decision matrix of five alternatives as shown in Table 7.

Table 7. The change fuzzy decision matrix of five alternatives

	S_0	S_1	S_2	S_3	S_4	S_5	Total
C_1	0.50	(0.5,0.21,0.13)	(0.5,0.2,0.1)	(0.5,0.2,0.1)	(0.5,0.21,0.13)	(0.5,0.19,0.1)	(3,1.52,1.05)
C_2	10	(0,4.44,10)	(2,4.1,10)	(2,6.88,10)	(2,8.26,10)	(2,5.1,8)	(18,38.77,58)
C_3	10	(2,5.86,10)	(2,4.98,10)	(2,5.1,8)	(2,6.88,10)	(0,4.44.10)	(18,37.26,58)
C_4	0.50	(0.5,0.2,0.13)	(0.5,0.23,0.13)	(0.5,0.21,0.13)	(0.5,0.15,0.1)	(0.5,0.19,0.1)	(3,1.48,1.08)
C_5	10	(4,7.13,10)	(4,4.7,10)	(0,5.65,10)	(2,5.1,8)	(2,7.04.10)	(22,39.63,58)

Step 5. Using Eqs (18)–(19) and Table 7, the normalized fuzzy decision making matrix as shown in Table 8.

Table 8. The normalized fuzzy decision making matrix

	S_0	S_1	S_2	S_3	S_4	S_5
C_1	(0.48,0.33,0.17)	(0.48,0.14,0.04)	(0.48,0.13,0.03)	(0.48,0.13,0.03)	(0.48,0.14,0.04)	(0.48,0.13,0.03)
C_2	(0.17,0.26,0.56)	(0,0.11,0.56)	(0.03,0.11,0.56)	(0.03,0.18,0.56)	(0.03,0.21,0.56)	(0.03,0.13,0.44)
C_3	(0.17,0.27,0.56)	(0.03,0.16,0.56)	(0.03,0.13,0.56)	(0.03,0.14,0.44)	(0.03,0.18,0.56)	(0,0.12,0.56)
C_4	(0.47,0.34,0.17)	(0.47,0.13,0.04)	(0.47,0.16,0.04)	(0.47,0.14,0.04)	(0.47,0.1,0.03)	(0.47,0.13,0.03)
C_5	(0.17,0.25,0.17)	(0.07,0.18,0.45)	(0.07,0.12,0.45)	(0,0.14,0.45)	(0.03,0.13,0.36)	(0.03,0.18,0.45)

Step 6. By using Eqs (20)–(24), the normalized-weighted fuzzy decision making matrix and solution results as shown in Table 9.

Table 9. The normalized-weights fuzzy decision making matrix and ARAS-F solution results

	S_0	S_1	S_2	S_3	S_4	S_5
C_1	(0.1,0.2,0.17)	(0.1,0.09,0.04)	(0.1,0.08,0.03)	(0.1,0.08,0.03,)	(0.1,0.09,0.04)	(0.1,0.08,0.03)
C_2	(0.07,0.14,0.44)	(0,0.06,0.44)	(0.01,0.06,0.44)	(0.01,0.1,0.44)	(0.01,0.12,0.44)	(0.01.0.07.0.36)
C_3	(0.07,0.2,0.56)	(0.01,0.12,0.56)	(0.01,0.1,0.56)	(0.01,0.1,0.44)	(0.01,0.14,0.56)	(0,0.09,0.56)
C_4	(0.09,0.17,0.13)	(0.09,0.07,0.03)	(0.09,0.08,0.03)	(0.09,0.07,0.03)	(0.09,0.05,0.03)	(0.09,0.07,0.03)
C_5	(0.03,0.17,0.13)	(0.01,0.12,0.45)	(0.01,0.08,0.45)	(0,0.09,0.45)	(0.01,0.09,0.36)	(0.01,0.12,0.45)
$\tilde{P}_i$	(0.36,0.89,1.47)	(0.22,0.46,1.53)	(0.23,0.4,1.52)	(0.22,0.45,1.41)	(0.22,0.48,1.43)	(0.21,0.43,1.43)
P_i	0.908	0.734	0.717	0.693	0.712	0.687
K_i	1	0.809	0.790	0.763	0.784	0.757

Step 7. Using Eq. (25), the normalized-weights for each green supplier were calculated K_i values as S_1 (0.809) > S_2 (0.790) > S_4 (0.784) > S_3 (0.763) > S_5 (0.757) (as shown in Table 9).

Step 8. According to the normalized-weights ($K_i, i = 1,2,...,5$) obtained from Step 7 for each green supplier in Table 9 is used as priority value (e.g., to maximization of green supplier goal) to build the MSGP achievement model to fine the best green supplier selection.

In addition, according to the sales record in last 5 years and the supplier's research by FCL, the coefficients of variables in green supplier's selection profiles shown in Table 10 represent the data set and ranges for each green supplier.

Table 10. Green supplier data from FCL's research

Suppliers	Technology capability items	Average purchase cost (US$ / 2 week)	Environment skill items
S_1	8 ~ 11	14,000 ~ 15,900	4
S_2	4 ~ 7	14,500	6
S_3	4	13,150 ~ 14,000	5
S_4	4 ~ 6	14,000	5
S_5	5	15,600	7

Moreover, according to business strategic by FCL, the top managers of FCL established objective is to determine the green supplier with such as the selection highest weighted of green supplier (G_1), technology capability items (G_2), the average purchase cost (G_3), and environment skill in negative items (G_4).

The MSGP model for the green supplier selection problems is set below:

G_1: $f_1(x) = 1$, the maximization of green supplier weights;

G_2: $f_2(x) \geq 10$, the maximization of technology capability items;

G_3: $f_3(x) \leq 435{,}000$, the minimization of purchase cost;

G_4: $f_4(x) \geq 6$, the maximization of environment skill items.

MSGP model

$\text{Min } Z = d_1^+ + d_1^- + d_2^+ + d_2^- + d_3^+ + d_3^- + d_4^+ + d_4^- + e_1^+ + e_1^- + e_2^+ + e_2^- + e_3^+ + e_3^- + e_4^+ + e_4^- + e_5^+ + e_5^-$	Satisfy all obligatory goals	(34)
s.t. $0.809x_1 + 0.790x_2 + 0.763x_3 + 0.784x_4 + 0.757x_5 - d_1^+ + d_1^- = 1$	For weighted of green supplier goal	(35)
$(11b_1 + 8(1 - b_1))\, x_1 + (7b_2 + 4(1 - b_2))x_2 + 4x_3 + (6b_3 + 4(1 - b_3))x_4 + 5x_5 - d_2^+ + d_2^- \geq 10$	Maximization of technology capability items	(36)
$(1/3)(\, 11\text{b}_1 + 8(1 - b_1)) - e_1^+ + e_1^- = 4.67$	Maximization of f technology capability items for S_1	(37)
$(1/3)(7b_2 + 4(1 - b_2)) - e_2^+ + e_2^- = 3.33$	Maximization of technology capability items for S_2	(38)
$(1/2)(6b_3 + 4(1 - b_3)) - e_3^+ + e_3^- = 4$	Maximization of technology capability items for S_4	(39)
$(15{,}900b_4 + 14{,}000(1 - b_4))\, x_1 + 14{,}500\, x_2 + (14{,}000b_5 + 13{,}150(1 - b_5))\, x_3 + 14{,}000x_4 + 15{,}600x_5 - d_3^+ + d_3^- \leq 435{,}000$	Representing purchase cost minimization	(40)
$(1/1{,}900)\,(15{,}900b_4 + 14{,}000(1 - b_4)) - e_4^+ + e_4^- = 8.37$	Minimization of purchase cost for S_1	(41)
$(1/850)\,(14{,}000b_5 + 13{,}150(1 - b_5)) - e_5^+ + e_5^- = 16.47$	Minimization of purchase cost for S_3	(42)
$4x_1 + 6x_2 + 5x_3 + 5x_4 + 7x_5 - d_4^+ + d_4^- \geq 6$	Maximization of environment skill items	(43)
$b_i \in \{0, 1\},\ i = 1, 2, \ldots, 5$	Represents the binary number	(44)
$d_i^+, d_i^- \geq 0,\ i = 1, 2, \ldots, 4$	Deviation from the target	(45)
$e_i^+, e_i^- \geq 0,\ i = 1, 2, \ldots, 5$	Deviation from the target	(46)

The MSGP model was solved using LINGO software (Schrage 2002) on a Pentium(R) 4 CPU 2.00 GHz-based microcomputer in a few seconds of computer processing time. The solutions are $Z = 0.4218$, $x_4 = 1$ and $x_1 = x_2 = x_3 = x_5 = 0$. Therefore, based on involvement quantitative measures in the best interest of the FCL, green supplier S_4 should be selected. This is a different result due to the MSGP method considered qualitative and quantitative selection criteria. Table 11 shows the results for green supplier selection comparisons with ARAS-F and MSGP methods.

Table 11. Comparison of green supplier selection methods

Methods	The best selection	Selection criteria		Multiple segment aspiration levels
		Qualitative	Quantitative	
ARAS-F (K_i ranking)	S_1	Yes	No	No
ARAS-F + MSGP (Using LINGO)	S_4	Yes	Yes	Yes

Conclusions

Green supplier selection is one of the critical decision-making activities to obtain competitive advantage and achieve GSCM goals. To achieve this firm's objective, the DMs should apply the best method and accurate criteria to solve green supplier selection problems. In general, green supplier evaluation and selection problems are vague and uncertain, and so fuzzy set theory helps to convert DM preferences and experiences into meaningful results by applying linguistic values to measure each criterion with respect to every supplier.

This paper proposes a new novel integration technique using FAHP, ARAS-F and MSGP to evaluate and select the best supplier. Given that many multiple segment aspiration levels may exist, a multiple segment approach is most appropriate for this type of decision-making. Therefore, this integrated method allows for the vague segment aspirations of DMs to set multiple aspiration levels for green supplier selection problems. The proposed advantage of this method is that it allows for the vague aspirations of DMs to set multiple segment aspiration levels (e.g., qualitative and quantitative criteria) for green supplier selection in which "the more/higher is better" (e.g., benefit criteria) or "the less/lower is better" (e.g., cost criteria). To the best of our knowledge, no work has been done for solving green suppliers selection problems, by using a integrate fuzzy AHP, ARAS-F and MSGP method. Table 12 presents a comparison and the discoveries of this proposed analytical method and the others.

The main limitation of the proposed model is that vagueness and imprecision of goals, constraints and parameters may exist in a green supplier selection problem, which make decision-making more complicated. Thus, future studies may consider green supplier selection problems in a fuzzy context. In addition, the proposed method may be useful for various FMCDM problems, such as marketing problems (e.g., new products development and promotion activities) and management problems (e.g., project management and location selection) when available data are vague, imprecise and uncertain by nature.

Table 12. Comparison of green supplier selection methods

Methods	Selection criteria		Multiple segment aspiration levels
	Qualitative	Quantitative	
AHP /ANP	Yes	No	No
LP / GP	No	Yes	No
DEA	No	Yes	No
CBE	No	Yes	No
GA	No	Yes	No
NN	Yes	No	No
TOPSIS	Yes	No	No
AHP (or ANP)+TOPSIS	Yes	No	No
ARAS-F	Yes	No	No
This proposed method (Fuzzy AHP+ARAS-F+MSGP)	Yes	Yes	Yes

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APPENDIX

The Nominal Group Technique (NGT) forces everyone to participate and no dominant person is allowed to come out and control the proceedings. In NGT, all ideas have equal stature and will be judged impartially by the group (Liao 2013a). The NGT procedure can be shorted four steps as: (a) silent generation of ideas in writing, (b) round-robin recording of ideas, (c) serial discussion of the list of ideas, and (d) take voting. NGT is applied in this work, we have a set of *n* criteria, $C = \{C_1, C_2, ..., C_n\}$ defined and described; with which green supplier performance is measured. Thus, criteria can be classified into two types as benefit criteria C^b and cost criteria C^c. Then $C = C^b \cap C^c$ and $C^b \cap C^c = \varphi$, where φ denote an empty set (Sarami *et al.* 2009; Liao 2013a).

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