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An approach for green supplier selection in the automobile manufacturing industry

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Abstract

Purpose – The purpose of this paper is to study a modified multiplicative analytic hierarchy process (MMAHP) method, which is combined with multi-criteria decision making (MCDM) and applied MMAHP model for solving green supplier selection problem.

Design/methodology/approach – Supplier selection is typically a MCDM problem including both qualitative and quantitative factors that has to be taken into consideration. To select the best green suppliers with the highest potential for meeting a firm's needs consistently, the MMAHP is utilized in this study. Then a green supplier selection problem of a well-known automobile manufacturing company in Qingdao is investigated. The authors also make a comparison of the results with that of the traditional AHP, during which the authors observe that the MMAHP is an effective approach for the considered problem and potential rank reversals can be avoided, that is, when a new supplier is added, the ranking of suppliers does not change and maintains its original relative ratio.

Findings – A numerical example of green supplier selection is utilized to verify the proposed approach. The results show that the MMAHP is an effective approach for the considered problem and potential rank reversals can be avoided.

Practical implications – The proposed approach can be used to solving green supplier selection problems and can avoid the rank reversal.

Originality/value – The paper introduces the MMAHP method to help researchers to choose more effective approach for green supplier selection.

Keywords Operational research, Green supply chain management, Supplier selection, Modelling, Modified multiplicative AHP (MMAHP)

Paper type Research paper

1. Introduction

In a competitive market environment, the selection of suppliers is an important decision making problem for a successful firm (Noci, 1997; Sarkis, 2003). Over the past two decades, the environmental problem has attracted wide attention from society. In order to balance environmental, economic and social performance to achieve sustainable development, suppliers need to implement efficient green strategies and reduce the environment impacts in the entire supply chain during the production, sale, after-sale service and disposal of recycle products (Min and Galle, 1997; Rao, 2002; Walton *et al.*, 1998). For a firm to select a supplier, it has to consider such factors as cost, service, quality, etc., and also the environmental impact as well (Rao and Holt, 2005; Zhu *et al.*, 2005). For such case, the green supply chain management (GSCM) has emerged not only as a generally recognized standard for firms to monitor suppliers according to their environmental performance (Hsu and Hu, 2009; Huang and Keskar, 2007), but also as a way to help the suppliers who proactively implement GSCM gain more profits and market shares (Diabat and Govindan, 2011; Van Hoek, 1999).

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Green supplier selection is a typical multi-criteria decision making (MCDM) problem, which involves both qualitative and quantitative factors (Fu *et al.*, 2012; Kainuma and Tawara, 2006; Lu *et al.*, 2007; Sevkli *et al.*, 2007; Wu, 2009). The goal of green supplier selection is to evaluate suppliers for satisfying a firm's standard by using a set of criteria and measures. There are various approaches for evaluation of green suppliers (Chan and Kumar, 2007; Deng *et al.*, 2014; Hsu *et al.*, 2013; Kannan *et al.*, 2008; Lee *et al.*, 2009; Tsai and Hung, 2009).

Kannan *et al.* (2008) utilized AHP method to green supplier selection and proved that the application of AHP in selection of CAD/CAM systems for manufacturing firms improved the decision making efficiency. Hsu and Hu (2009) presented an analytic network process (ANP) approach to incorporate the issue of hazardous substance management into supplier selection. Lee *et al.* (2009) proposed a fuzzy AHP model with the consideration of benefits, opportunities, costs and risks to evaluate green suppliers for an anonymous TFT-LCD manufacturer in Taiwan. Awasthi *et al.* (2010) presented a fuzzy TOPSIS approach for evaluating environmental performance of suppliers under fuzzy environment. Buyukozkan and Cifci (2012) also proposed a hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. Tseng and Chiu (2013) proposed a hybrid MCDM approach to deal with GSCM in linguistic preferences, quantitative data and incomplete information. Hruska *et al.* (2014) dealt with supplier selection using AHP, which provided a framework for making effective decisions in complex decision situations (e.g. vendor selection), helps to simplify and accelerate the natural process of decision making. Beikkhakhian *et al.* (2014) proposed the application of ISM model in evaluating agile suppliers selection criteria and ranking suppliers using fuzzy TOPSIS-AHP methods. Karsak and Dursun (2015) proposed an integrated fuzzy MCDM approach for supplier evaluation and selection. The proposed methodology seeks to establish the relevant supplier assessment criteria while also considering the impacts of inner dependence among them. Cárdenas-Barrón *et al.* (2015) dealt with the multi-product multi-period inventory lot sizing with supplier selection problem. Geng and Liu (2015) developed a hybrid service supplier selection approach based on variable precision rough set and VIKOR for developing product service system. Chen (2015) proposed a group selection approach to supplier collaborative configuration problems with correlation of experts and attributes. Simic *et al.* (2015) presented a novel hybrid model for supplier assessment and selection, based on hybrid solution including genetic algorithm and harmony search algorithm. Hashemi *et al.* (2015) used both economic and environmental criteria and proposed a comprehensive green supplier selection model. They used ANP to calculate the criteria weights. Kar (2015) investigated a hybrid group decision support system for supplier selection using analytic hierarchy process, fuzzy set theory and neural network. Moghaddam (2015) developed a fuzzy multi-objective mathematical model to identify and ranked the candidate suppliers and found the optimal number of new and refurbished parts and final products in a reverse logistics network configuration. You *et al.* (2015) proposed an extended VIKOR method for group multi-criteria supplier selection with interval two-tuple linguistic information. Memon *et al.* (2015) applied the combination of grey system theory and uncertainty theory which neither required any probability distribution nor fuzzy membership function. Pitchipoo *et al.* (2015) presented an alternative decision model to evaluate the relative performance of suppliers which has multiple outputs and inputs. Freeman and Chen (2015) focussed on development of a green supplier selection model using an AHP-Entropy-TOPSIS framework based on a combination of traditional supplier and environmental supplier selection criteria.

One of the widely preferred methods is AHP (Chan and Kumar, 2007). It is an efficient technique for multiple criteria analyses due to its computational simplicity and effectiveness in solving supplier selection problem. However, AHP is often criticized regarding its rank reversal phenomenon. In this phenomenon, the alternatives' order changes when an alternative is removed from or added to the original alternative set. In some cases, the rank of alternatives is totally inverted, that is, the alternative is considered the best, and then it becomes the worst after adding or deleting an alternative. Such a phenomenon may not be acceptable in some situations. At present, to overcome this issue, an alternative approach called modified multiplicative analytic hierarchy process (MMAHP) was proposed to effectively solve rank reversal (Hou, 2011, 2012, 2014a, b). The method contained the following aspects: first, the newly criterion was introduced to check acceptable consistency; second, the row's geometric mean method was used for deriving the local weights; third, a hierarchy composition rule was proposed to compute the sub-criterion's global weights; fourth, the weighted geometric mean method was used as the aggregation rule, where the alternative's local weights were min-normalized. The MMAHP has the property of preserving rank and has counterparts in other cases. More details can be seen in the literatures (Hou, 2011, 2012, 2014a, b).

To select the best green supplier for an automobile manufacturing firm, the aim of this paper is to utilize the MMAHP for evaluating green suppliers. We then apply the MMAHP to an automobile firm for supplier selection, and also present comparative analysis of results with that of the traditional AHP in the context of changing the suppliers' numbers. The rest of the paper is organized as follows: Section 2 gives a brief introduction to the MMAHP. The proposed framework for prioritizing the solutions of green suppliers is described in Section 3. Section 4 presents the results of using the MMAHP in a real case application, and also compares the results of the proposed method with that of the traditional AHP. Section 5 discusses the conclusions about this research work and suggestions for further research.

2. Preliminaries

2.1 Multiplicative pairwise comparison matrix (PCM)

Let $X = \{x_1, x_2, ..., x_n\}$ be an object set, $I = \{1, 2, ..., n\}$ be an index set and i, j, k, l be index variables. Let α be a real number and $\alpha \in (1, +\infty)$ (Hou, 2014a).

For a PCM $M_{n\times n} = (p_{jk})_{n\times n}$ with $\forall j, k(p_{jk} \in [1/\alpha, \alpha])$, the conditions of reciprocity and consistency (multiplicative sense) are given by $\forall j, k(p_{jk}p_{kj} = 1)$ and $\forall j, k, l(p_{jl}p_{lk} = p_{jk})$, respectively. For a consistent multiplicative PCM $M_{n\times n} = (p_{jk})_{n\times n}$, a $n \times 1$ vector $W = (w_j)_{n\times 1}$ with $\forall j(w_j \in [1/\alpha, \alpha])$ is called a weight vector of $M_{n\times n} = (p_{jk})_{n\times n}$ such that $\forall j, k \in I, p_{jk}w_k = w_j$.

2.2 Method for deriving priorities

It is proved that the mean method can be used for deriving priorities from a consistent PCM (Hou, 2014a).

In the following, the priority vector corresponding to a consistent multiplicative PCM $M_{n\times n} = (p_{jk})_{n\times n}$ can be elicited by a geometric row mean method:

$$w_j = \left(\prod_{k=1}^{n} p_{jk}\right)^{\frac{1}{n}}, \quad j = 1, 2, \ ..., \ n$$

2.3 Min-normalization

Vector normalization is a widely used method to obtain uniqueness. The min-normalization is proposed (Hou, 2014a):

P1. If a multiplicative PCM is consistent, then there exists one and only one multiplicatively min-normalized vector (a multiplicatively min-normalized vector is a vector with all entries in [1, α] and at least one entry being 1) as its priority vector which is denoted by:

$$\overline{w}_i^{\min} = w_i / \min_k \{w_k\}$$

2.4 Hierarchy composition rule

Two Decomposition-Incorporation theorems are given in the following (Hou, 2014a):

P2. Suppose $D = \left(\overline{u}_{ij}\right)_{n\times m}$ and $B = (\beta_l)_{m\times 1}$, where $\beta_l > 0$ and $\sum_{l=1}^{m}\beta_l = 1$. If $\forall i, j\left(\overline{u}_{ij} > 0\right)$, we have:

$$r_j = \prod_{l=1}^{m}\left(\overline{u}_{jl}\right)^{\beta_l}$$

$$= \left(\prod_{l=1}^{t}\left(\overline{u}_{jl}\right)^{\frac{\beta_l}{\sum_{i=1}^{t}\beta_i}}\right)^{\sum_{i=1}^{t}\beta_i}\left(\prod_{l=t+1}^{m}\left(\overline{u}_{jl}\right)^{\frac{\beta_l}{\sum_{i=t+1}^{m}\beta_i}}\right)^{\sum_{i=t+1}^{m}\beta_i}, \quad j = 1, 2, \ldots, n$$

P3. Suppose $D = \left(\overline{u}_{ij}\right)_{n\times m}$ and $B = (\beta_l)_{m\times 1}$, where $\beta_l > 0$ and $\sum_{l=1}^{m}\beta_l = 1$. If $\forall i, j\left(\overline{u}_{ij} > 0\right)$, we have:

$$O_j = \sum_{l=1}^{m}\beta_l\left(\overline{u}_{jl}\right)$$

$$= \left(\sum_{i=1}^{t}\beta_i\right)\sum_{l=1}^{t}\frac{\beta_l}{\sum_{i=1}^{t}\beta_i}\left(\overline{u}_{jl}\right)$$

$$+ \left(\sum_{i=t+1}^{m}\beta_i\right)\sum_{l=t+1}^{m}\frac{\beta_l}{\sum_{i=t+1}^{m}\beta_i}\left(\overline{u}_{jl}\right), \quad j = 1, 2, \ldots, n$$

The Decomposition-Incorporation theorems are simple and their forms are not unique. However, they indicate when and how to decompose and incorporate a MCDA problem.

2.5 Acceptable consistency criterion for PCMs

An acceptable consistency is defined as follows (Hou, 2014a):

- for two rows of a PCM, if the relation $\leqslant$ holds elementwise, or, if the relation $\geqslant$ holds elementwise, then, these two rows are in acceptable consistency;
- if any two rows are in acceptable consistency, then, the PCM has acceptable consistency.

Based on this intuitive definition, we propose the following acceptable criterion.

A multiplicative pairwise comparison matrix $M=(p_{ij})$ is of acceptable consistency if, and only if, the following condition is verified:

$$(p_{ik}>p_{jk})\rightarrow\forall l(p_{il}>p_{jl})$$

Clearly, we have, if a PCM $M=(p_{ij})$ is consistent, it must be acceptably consistent, since $p_{ij}=w_i/_{wj}$, where $w_i>0$ and $w_j>0$; it is not necessarily true that, when a PCM has acceptable consistency, it must be consistent.

2.6 Hierarchical model and steps

In the MMAHP method (Hou, 2014a), for one level to multi-level hierarchy decision model, the Decomposition-Incorporation Theorem can assure its possibility and practicability. For pairwise comparison based decision making, the counterparts of the multiplicative case and the fuzzy case indicated what we should do when we used hierarchical decision model to get overall priorities for alternatives.

The steps of the MMAHP decision model are involved as follows (Figure 1):

Step 1: break down the decision problem into a hierarchy of decision elements (goal as the top level, criteria and sub-criteria as the middle levels, and alternatives as the terminal level).

Step 2: establish the pairwise comparison matrix (PCM) based on a ratio scale for the decision elements in each level of the hierarchy with respect to one decision element at a time in the immediate upper level.

Step 3: determine whether or not the PCMs have acceptable consistency by indicator of inequality:

$$(p_{ik}>p_{jk})\rightarrow\forall l(p_{il}>p_{jl}). \tag{1}$$

If not, go back to Step 2 and redo the pairwise comparisons.

Step 4: derive the normalized local weight vectors from the PCMs using the row geometric mean method:

$$\omega_j=\left(\prod_{k=1}^{n}p_{jk}\right)^{\frac{1}{n}}. \tag{2}$$

If a local weight vector is of the criteria (sub-criteria) in a same level with respect to a specific decision element in the immediate upper level, it is then to be sum-normalized; if it is of the alternatives with respect to a terminal criterion, it is then to be min-normalized as indicated by:

$$\overline{w}_i^{\min}=\omega_i/\min_k\{\omega_k\}. \tag{3}$$

Step 5: compute the terminal sub-criteria (criteria) weights with respect to the total goal (using the following equation):

$$\beta_j^{(l+1)}=\beta_k^{(l)}\overline{\beta}_j^{(l+1)}, \tag{4}$$

where $\beta_j^{(l+1)}$ denotes the global weight of the sub-criterion with respect to the total goal, $\beta_k^{(l)}$ denotes the father-criterion's weight with respect to the total goal, $\overline{\beta}_j^{(l+1)}$ denote the local weight of a sub-criterion in level l +1 with respect to its immediately preceding criterion /sub-criterion in level (called the father-criterion).

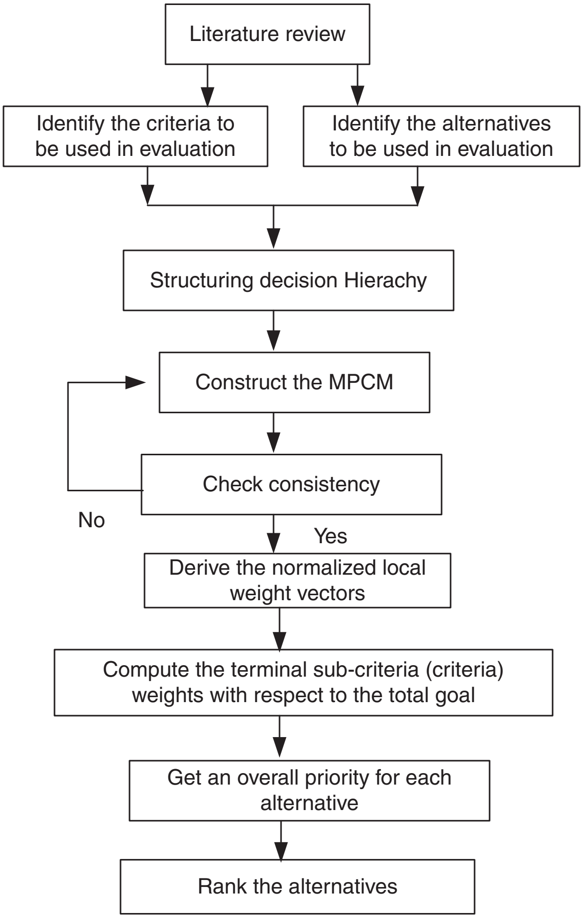

Figure 1.
The steps of MMAHP method

Step 6. to get an overall priority for each alternative, synthesize the alternative's local weights using the following weighted geometric mean aggregation rule:

$$r_j = \prod_{l=1}^{m} \overline{u}_{jl}^{\beta_l}, \tag{5}$$

where $\overline{u}_{jl}$ is the alternative's local weight (has been min-normalized in Step 4) with respect to the terminal sub-criterion, and β_l is the terminal sub-criterion's weight with respect to the total goal.

The difference between the MMAHP and the traditional AHP includes the following aspects: first, in the MMAHP, the condition of acceptable consistency is defined by $(p_{ik} > p_{jk}) \rightarrow \forall l(p_{il} > p_{jl})$; in the traditional AHP, the condition of acceptable consistency is defined by $CR < 0.1$; second, in the MMAHP, the row's geometric mean method is used for deriving the local weights; in the traditional AHP, the eigenvector method is applied to derive the local weights; third, in the MMAHP, the weighted geometric mean method is used as the aggregation rule; in the traditional AHP, the arithmetic row mean method is utilized as the aggregation rule; fourth, In the MMAHP, the alternative's local weights are min-normalized; in the traditional AHP, the alternative's local weights are sum-normalized.

The MMAHP also has several desirable traits. First, it has the property of preserving rank; second, it has counterparts in other cases, such as additive case and fuzzy case (Hou 2014a, b).

3. The MMAHP procedure to rank the green suppliers

The MMAHP for prioritizing green suppliers has the following three phases.

3.1 Phase 1: identification of green criteria and potential solutions of suppliers

In the first phase, a decision group of expert panels which comprising senior managers and project representatives are formed for the supplier criteria identification and evaluation. Then the criteria are determined through literature review and these experts' opinions. After the determination of criteria, another expert panel is formed for identification and evaluation of green suppliers. The expert panel consists of senior managers and senior executives. Then the hierarchy structure is formed such that objective is at the first level, main criteria are in the second level, sub-criteria are at third level and solutions are in the fourth level.

3.2 Phase 2: calculate the weight of suppliers' criteria

After forming a decision hierarchy, the pairwise comparison matrixes of criteria and sub-criteria are constructed to acquire criteria weights by using the scale in Table I. From these matrixes, the local weights of criteria and sub-criteria are calculated by row geometric mean and sum-normalized. Then the final weights of the sub-criteria with respect to the total goal are obtained by Equation (4).

3.3 Phase 3: evaluate the weight of solutions with respect to the sub-criteria and determine the final weights toward the total goal

The pairwise comparison matrixes of suppliers with respect to the sub-criteria are constructed. From these matrixes, the local weights of the suppliers with respect to the

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of tile highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Table I. The fundamental scale

sub-criteria are computed by geometric row mean and min-normalized. Then, the rating of solutions toward the total goal is determined according to the final weights values calculated by aggregation rule in descending order.

4. Case study

In this section, we apply the MMAHP to application of the green supplier selection based on environmental criteria in an automobile manufacturing firm. Firms should not only pursue environmental benefits, but also gain economic benefit and social benefit from environmental benefits in the whole green supply chain. In order to balance the relationship between the three benefits, it is necessary for automobile manufacturing firm to evaluate and select the green suppliers based on the green supply chain performance.

Over the past decades, automobile manufacturing firms have been under enormous pressure on actively improving supply chain environmental performance and reducing environmental influences. In order to increase their market share and profit, automobiles manufacturing firms need to implement green strategy at all stages of the manufacturing process and encourage suppliers to improve their environmental practices and performance. With the development of green supply chain, the firms must begin to implement several regulatory checks and programs to ensure that suppliers can provide products both with high quality and with high environmental standards. Since most of automobiles parts are produced by suppliers, the suppliers' selection based on their green criteria can improve the firm's environmental performance and competitive advantage. Thus, the green supplier selection is one of the most important decision making problems in the automobile manufacturing firm.

4.1 Case firm background

The case study is based on an automobile manufacturing firm that designs and manufactures cars in Qingdao. According to their management policies, the order qualification must be approved by IS09001 that is a quality management system, ISO14001 that is environment management system. Besides the environmental aspect, they also consider traditional criteria such as quality, cost, delivery, and service to measure suppliers' performances.

4.2 Criteria selection

In the automobile manufacturing firm for green supplier selection, several green criteria should be taken into account due to the great environmental pressure. All of the green supplier evaluation criteria have been derived from various ways, including green supplier selection literatures, experts' opinions, reference books, related organizations and so on. After referring to green and traditional supplier selection studies in Section 1, and the case company's opinions, we design and release a Delphi expert questionnaire to ten experts in the environment and supply chain to determine green supplier selection criteria. If the opinions of each expert are not consistent, the Delphi questionnaire must be modified until the questionnaire result is converged. The questionnaire is constructed based on Likert scale to show importance of each criterion. The criterion has lower total score, it must be omitted, and otherwise can be preserved. Based on the criteria derived from the above ways, the main criteria and the sub-criteria in this study are determined.

First, four main criteria are identified. The main criteria are product performance (C1), supplier criteria (C2), cooperation and development potential (C3) and green performance (C4). Product performance criteria can be used to measure the characteristics of product being purchased. Supplier criteria are evaluated whether the suppliers satisfy the expectation value of firms. Cooperation and development potential criteria can be used to evaluate the technology strategy and services level provided by the suppliers. Green performance criteria are used to evaluate whether the environmental performance of suppliers achieves the standard of firms. Then, the main criteria are decomposed into 14 sub-criteria. The sub-criteria are quality, price, cost, financial status, quality certification, social status, geographical position, business implementation capacity, development and innovation, technical ability, service level, green degree level, resources recycling ability and energy utilization ability. Finally, there are five possible green suppliers (A1, A2, A3, A4, and A5) for automobile manufacturing firm to evaluate and select. The sub-criteria are discussed in detail below.

Quality (C1-1): product quality is the main factor influencing the suppliers' competition in the market. Thus it becomes one of the most important factors in automobile manufacturers for supplier evaluation.

Price (C1-2): as an important measure of firms to select suppliers, price can not only show the competitiveness of suppliers, but also it is one of the main criteria of supplier selection.

Cost (C1-3): cost is the key of the automobile manufacturer for supplier evaluation, and it is mainly related to manufacturing cost, material cost, inventory cost and human resources cost of suppliers.

Financial status (C2-1): any supplier's development requires a certain amount of economic foundation, thus it is necessary to measure the financial status of suppliers.

Quality certification (C2-2): quality certification is a kind of scientific management system. It mainly focusses on whether the products of suppliers fit the regulations of product quality, including the quality assurance, quality control procedures, documentation, continuously quality improvement, etc.

Social status (C2-3): social status represents the social responsibility of suppliers. Maintaining the market competition vitality and ensuring the stability of economic operation are important evaluation indicators for supplier selection.

Geographical position (C2-4): the location of suppliers determines the delivery time and the transportation cost, and further affects the production cost.

Business implementation capacity (C3-1): in the GSCM, business implementation capacity is associated with economic performance and environmental protection performance of suppliers.

Development and innovation (C3-2): under the GSCM environment, suppliers must be innovative by combining the environmental performance and economic performance to improve their competitiveness.

Technical ability (C3-3): technical ability reflects the internal technical potential and the improvements ability according to changing in firm's needs in the future.

Service level (C3-4): with increasingly fierce competition in automobile manufacturing and ever-growing demands of product delivery and flexibility, the suppliers' service level is directly related to the competitiveness of automobile manufacturers. The suppliers' service level evaluation mainly focusses on product delivery, flexibility, information and logistics, etc.

Green degree level (C4-1): green degree level usually refers to the influence degree of suppliers on the environment or their friendly degree to the environment. It is the core evaluation indicators in the automobile manufacturing firm when selecting green suppliers.

Resources recycling ability (C4-2): resources recycling ability reflects the recycling rate of products and the contribution degree of suppliers to the environmental protection.

Energy utilization ability (C4-3): energy utilization ability represents the resource allocation degree and energy utilization rate of suppliers in the entire green supply chain.

4.3 MMAHP for supplier selection in the automobile manufacturing firm

In the supplier selection problem, the relative importance of arguments shows the high degree of subjective judgment and individual preferences. Here, the MMAHP method is used to decide the final priority weights of suppliers. The first step of this study is to define the model for MMAHP with respect to the automobile industry for selecting suppliers from green supply chain perspective. In the following, the main steps of the method are explained in detail.

There are four levels in decision hierarchy structure for this problem. The overall goal of decision process determined as "ranking the solutions of green suppliers" is in the first level of hierarchy. The main criteria are located on the second level, the sub-criteria are at third level and the potential suppliers are in the fourth level of hierarchy. Figure 2 shows the hierarchical representation of selecting the best green supplier in the automobile industry.

After that, the method performs a pairwise comparison of four main criteria and 14 sub-criteria by using Table I. The pairwise comparison matrixes of criteria and sub-criteria are given in Table II. The pairwise comparison matrixes of suppliers with respect to each sub-criterion are shown in Table III.

Since all the pairwise comparison matrixes are of satisfied consistency by the indicator of inequality (1), the local weights of criteria can be solved by Equation (2) and sum-normalized. Then the weights of terminal sub-criteria with respect to the total goal are obtained by Equation (4) shown in Table IV. Meantime, the priority weights of criteria are solved by the traditional AHP shown in Table IV. Moreover, each supplier's local weight with respect to the sub-criteria is given by Equation (2) and min-normalized shown in Table V.

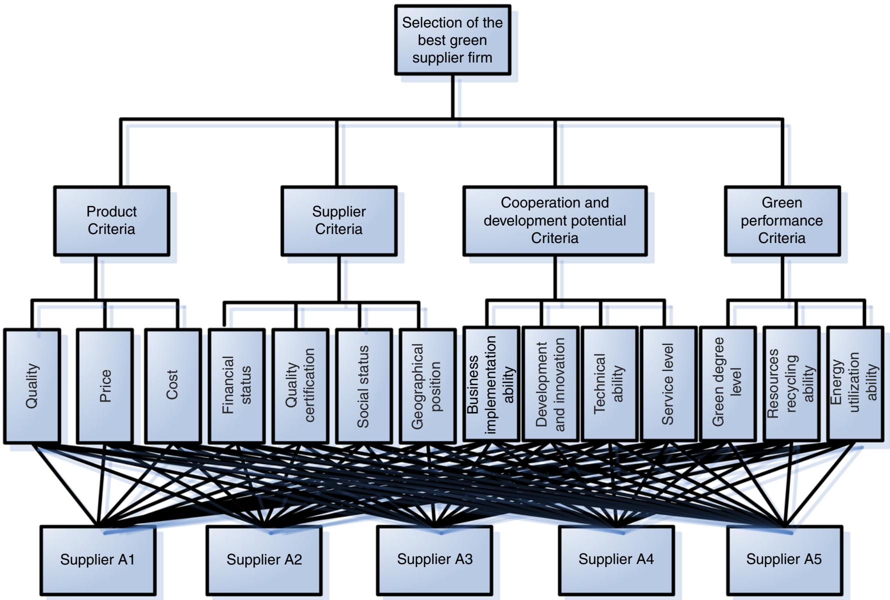

Figure 2.
Hierarchical structure of green supplier selection

C1,C2,C3 w.r.t. the total goal

$$\begin{pmatrix} 1 & 2 & 3 & 3 \\ 1/2 & 1 & 2 & 3 \\ 1/2 & 1/2 & 1 & 2 \\ 1/3 & 1/3 & 1/2 & 1 \end{pmatrix}$$

C1-1,C1-2,C1-3 w.r.t. C1

$$\begin{pmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{pmatrix}$$

C2-1,C2-2,C2-3,C2-4 w.r.t. C2

$$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 1/2 & 1 & 2 & 3 \\ 1/3 & 1/2 & 1 & 3 \\ 1/4 & 1/3 & 1/3 & 1 \end{pmatrix}$$

C3-1,C3-2,C3-3,C3-4 w.r.t. C3

$$\begin{pmatrix} 1 & 2 & 1/2 & 1/3 \\ 1/2 & 1 & 1/3 & 1/4 \\ 2 & 3 & 1 & 1 \\ 3 & 4 & 1 & 1 \end{pmatrix}$$

C4-1,C4-2,C4-3 w.r.t. C4

$$\begin{pmatrix} 1 & 1/2 & 1/3 \\ 2 & 1 & 1/2 \\ 3 & 2 & 1 \end{pmatrix}$$

Table II. PCMs of criterion w.r.t criterion

Based on Equation (5), we can obtain the final priorities of suppliers as: 3.2659, 3.0128, 2.4674, 2.1905, 1.7921.

Thus, the ranking of the considered green suppliers is:

$$A1 \succ A2 \succ A3 \succ A4 \succ A5.$$

Here is a comparison of results by using the MMAHP and the traditional AHP as shown in Table VI.

At this time, a supplier A6 is added, and then the pairwise comparison matrixes of suppliers with respect to the sub-criteria are shown in Table VII.

Then, the final performance rating of suppliers with respect to the sub-criteria is solved by the above similar calculation steps shown as Table VIII.

Based on Equation (5), we can obtain the overall priorities of suppliers as: 3.1279, 2.9442, 2.4574, 2.2013, 1.7686, 1.7686.

Thus, the ranking of the considered green suppliers is:

$$A1 \succ A2 \succ A3 \succ A4 \succ A5 \succ A6.$$

Here is also a comparison of results by using the MMAHP and the traditional AHP as shown in Table IX.

Based on the above mentioned, it can be seen that the order of supplier A3, A4, A5 is changed by using the traditional AHP when adding a supplier A6, while the order of all suppliers is same and maintains its original ratio by using the MMAHP.

4.4 Result and discussions

In the green supplier selection process, the evaluation of a different set of supplier alternatives may require the inclusion or exclusion of suppliers. In this case, the used selection method must produce a consistent preference order of suppliers.

In the MMAHP application case, with five suppliers for all criteria, the outranking is $A1 \succ A2 \succ A3 \succ A4 \succ A5$. To verify the MMAHP method, an additional supplier

Table III.
PCMs of suppliers w.r.t terminal criteria

A1,A2,A3,A4,A5 w.r.t. C1-1
$$\begin{pmatrix} 1 & 2 & 3 & 3 & 5 \\ 1/2 & 1 & 2 & 2 & 4 \\ 1/3 & 1/2 & 1 & 2 & 3 \\ 1/3 & 1/2 & 1/2 & 1 & 2 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C1-2
$$\begin{pmatrix} 1 & 3 & 4 & 4 & 5 \\ 1/3 & 1 & 3 & 3 & 4 \\ 1/4 & 1/3 & 1 & 2 & 3 \\ 1/4 & 1/3 & 1/2 & 1 & 2 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C1-3
$$\begin{pmatrix} 1 & 1/2 & 1/3 & 1/3 & 1/4 \\ 2 & 1 & 1/2 & 1/2 & 1/3 \\ 3 & 2 & 1 & 1 & 1/2 \\ 3 & 2 & 1 & 1 & 1/2 \\ 4 & 3 & 2 & 2 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C2-1
$$\begin{pmatrix} 1 & 1/2 & 1/2 & 1/3 & 1/3 \\ 2 & 1 & 1 & 1/2 & 1/2 \\ 2 & 1 & 1 & 1 & 1/2 \\ 3 & 2 & 1 & 1 & 1 \\ 3 & 2 & 2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C2-2
$$\begin{pmatrix} 1 & 2 & 3 & 3 & 4 \\ 1/2 & 1 & 3 & 3 & 3 \\ 1/3 & 1/3 & 1 & 2 & 2 \\ 1/3 & 1/3 & 1/2 & 1 & 1 \\ 1/4 & 1/3 & 1/2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C2-3
$$\begin{pmatrix} 1 & 3 & 3 & 4 & 6 \\ 1/3 & 1 & 2 & 3 & 5 \\ 1/3 & 1/2 & 1 & 2 & 4 \\ 1/4 & 1/3 & 1/2 & 1 & 3 \\ 1/6 & 1/5 & 1/4 & 1/3 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C2-4
$$\begin{pmatrix} 1 & 1/2 & 1/3 & 1/3 & 1/4 \\ 2 & 1 & 1/3 & 1/3 & 1/3 \\ 3 & 3 & 1 & 1 & 1/2 \\ 3 & 3 & 1 & 1 & 1 \\ 4 & 3 & 2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C3-1
$$\begin{pmatrix} 1 & 1 & 2 & 3 & 3 \\ 1 & 1 & 3 & 4 & 5 \\ 1/2 & 1/3 & 1 & 5 & 6 \\ 1/3 & 1/4 & 1/5 & 1 & 6 \\ 1/3 & 1/5 & 1/6 & 1/6 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C3-2
$$\begin{pmatrix} 1 & 1/2 & 1/3 & 1/4 & 1/4 \\ 2 & 1 & 1/2 & 1/3 & 1/3 \\ 3 & 2 & 1 & 1/2 & 1 \\ 4 & 3 & 2 & 1 & 2 \\ 4 & 3 & 1 & 1/2 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C3-3
$$\begin{pmatrix} 1 & 2 & 3 & 4 & 4 \\ 1/2 & 1 & 3 & 3 & 3 \\ 1/3 & 1/3 & 1 & 1 & 2 \\ 1/4 & 1/3 & 1 & 1 & 2 \\ 1/4 & 1/3 & 1/2 & 1/2 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C3-4
$$\begin{pmatrix} 1 & 1/3 & 1/4 & 1/4 & 1/5 \\ 3 & 1 & 1/3 & 1/3 & 1/4 \\ 4 & 3 & 1 & 1/2 & 1/3 \\ 4 & 3 & 2 & 1 & 1/2 \\ 5 & 4 & 3 & 2 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C4-1
$$\begin{pmatrix} 1 & 3 & 4 & 5 & 5 \\ 1/3 & 1 & 3 & 4 & 4 \\ 1/4 & 1/3 & 1 & 2 & 3 \\ 1/5 & 1/4 & 1/2 & 1 & 2 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C4-2
$$\begin{pmatrix} 1 & 2 & 4 & 4 & 5 \\ 1/2 & 1 & 3 & 3 & 4 \\ 1/4 & 1/3 & 1 & 2 & 3 \\ 1/4 & 1/3 & 1/2 & 1 & 2 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5 w.r.t. C4-3
$$\begin{pmatrix} 1 & 1/2 & 1/3 & 1/4 & 1/5 \\ 2 & 1 & 1/2 & 1/3 & 1/4 \\ 3 & 2 & 1 & 1/2 & 1/3 \\ 4 & 3 & 2 & 1 & 1/2 \\ 4 & 4 & 3 & 2 & 1 \end{pmatrix}$$

Main criteria	Local weight AHP	Local weight MMAHP	sub-criteria	Local weight AHP	Local weight MMAHP	Final weight AHP	Final weight MMAHP
Supplier	0.4400	0.4380	Quality	0.5396	0.5396	0.2376	0.2364
			Price	0.2970	0.2970	0.1307	0.1301
			Cost	0.1634	0.1634	0.0720	0.0716
Product	0.2785	0.2798	Financial status	0.4620	0.4632	0.1287	0.1296
			Quality certification	0.2739	0.2754	0.0763	0.0771
			Social status	0.1780	0.1760	0.0496	0.0493
			Geographical position	0.0862	0.0854	0.0240	0.0239
Cooperation and development potential	0.1779	0.1788	Business implementation capacity	0.1640	0.1638	0.0292	0.0293
			Development and innovation	0.0972	0.0974	0.0173	0.0174
			Technical ability	0.3370	0.3375	0.0600	0.0603
			Service level	0.4018	0.4013	0.0715	0.0718
Green performance	0.1033	0.1032	Green degree level	0.1634	0.1634	0.0169	0.0169
			Resources recycling ability	0.2970	0.2970	0.0307	0.0307
			Energy utilization ability	0.5396	0.5396	0.0557	0.0557

Table IV. Priority weights of criteria in the MMAHP and AHP

Sub-criteria	Suppliers A1	A2	A3	A4	A5
Quality (C1-1)	6.4074	3.9487	2.6052	1.8206	1.0000
Price (C1-2)	7.7961	4.2823	2.2679	1.5849	1.0000
Cost (C1-3)	1.0000	1.6438	2.9302	2.9302	5.1017
Financial status (C2-1)	1.0000	1.7826	2.0477	2.9302	3.3659
Quality certification (C2-2)	4.4413	3.1777	1.6055	1.0592	1.0000
Social status (C2-3)	9.5094	5.1435	3.4375	2.1411	1.0000
Geographical position (C2-4)	1.0000	1.3977	3.1777	3.6502	4.4413
Business implementation capacity (C3-1)	6.2738	7.9819	4.8559	2.2206	1.0000
Development and innovation (C3-2)	1.0000	1.6055	3.1037	5.4038	3.5652
Technical ability (C3-3)	5.4038	3.6502	1.6055	1.5157	1.0000
Service level (C3-4)	1.0000	1.8206	3.4375	4.9190	7.7961
Green degree level (C4-1)	8.1519	4.5359	2.2679	1.4310	1.0000
Resources recycling ability (C4-2)	7.1889	4.6440	2.2679	1.5849	1.0000
Energy utilization ability (C4-3)	1.0000	1.9743	2.6052	4.2823	6.4907

Table V. Ratings of suppliers under various sub-criteria

Method	A1	A2	A3	A4	A5	Ranking
MMAHP	3.2659	3.0128	2.4674	2.1905	1.7921	$A1 \succ A2 \succ A3 \succ A4 \succ A5$
AHP	0.2902	0.2134	0.1664	0.1605	0.1695	$A1 \succ A2 \succ A5 \succ A3 \succ A4$

Table VI. The compromise solutions by different methods

Table VII.
PCMs of suppliers w.r.t terminal criteria

A1,A2,A3,A4,A5,A6 w.r.t. C1-1
$$\begin{pmatrix} 1 & 2 & 3 & 3 & 5 & 5 \\ 1/2 & 1 & 2 & 2 & 4 & 4 \\ 1/3 & 1/2 & 1 & 2 & 3 & 3 \\ 1/3 & 1/2 & 1/2 & 1 & 2 & 2 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 & 1 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C1-2
$$\begin{pmatrix} 1 & 3 & 4 & 4 & 5 & 5 \\ 1/3 & 1 & 3 & 3 & 4 & 4 \\ 1/4 & 1/3 & 1 & 2 & 3 & 3 \\ 1/4 & 1/3 & 1/2 & 1 & 2 & 2 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 & 1 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C1-3
$$\begin{pmatrix} 1 & 1/2 & 1/3 & 1/3 & 1/4 & 1/4 \\ 2 & 1 & 1/2 & 1/2 & 1/3 & 1/3 \\ 3 & 2 & 1 & 1 & 1/2 & 1/2 \\ 3 & 2 & 1 & 1 & 1/2 & 1/2 \\ 4 & 3 & 2 & 2 & 1 & 1 \\ 4 & 3 & 2 & 2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C2-1
$$\begin{pmatrix} 1 & 1/2 & 1/2 & 1/3 & 1/3 & 1/3 \\ 2 & 1 & 1 & 1/2 & 1/2 & 1/2 \\ 2 & 1 & 1 & 1 & 1/2 & 1/2 \\ 3 & 2 & 1 & 1 & 1 & 1 \\ 3 & 2 & 2 & 1 & 1 & 1 \\ 3 & 2 & 2 & 1 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C2-2
$$\begin{pmatrix} 1 & 2 & 3 & 3 & 4 & 4 \\ 1/2 & 1 & 3 & 3 & 3 & 3 \\ 1/3 & 1/3 & 1 & 2 & 2 & 2 \\ 1/3 & 1/3 & 1/2 & 1 & 1 & 1 \\ 1/4 & 1/3 & 1/2 & 1 & 1 & 1 \\ 1/4 & 1/3 & 1/2 & 1 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C2-3
$$\begin{pmatrix} 1 & 3 & 3 & 4 & 6 & 6 \\ 1/3 & 1 & 2 & 3 & 5 & 5 \\ 1/3 & 1/2 & 1 & 2 & 4 & 4 \\ 1/4 & 1/3 & 1/2 & 1 & 3 & 3 \\ 1/6 & 1/5 & 1/4 & 1/3 & 1 & 1 \\ 1/6 & 1/5 & 1/4 & 1/3 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C2-4
$$\begin{pmatrix} 1 & 1/2 & 1/3 & 1/3 & 1/4 & 1/4 \\ 2 & 1 & 1/3 & 1/3 & 1/3 & 1/3 \\ 3 & 3 & 1 & 1 & 1/2 & 1/2 \\ 3 & 3 & 1 & 1 & 1 & 1 \\ 4 & 3 & 2 & 1 & 1 & 1 \\ 4 & 3 & 2 & 1 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C3-1
$$\begin{pmatrix} 1 & 1 & 2 & 3 & 3 & 3 \\ 1 & 1 & 3 & 4 & 5 & 5 \\ 1/2 & 1/3 & 1 & 5 & 6 & 6 \\ 1/3 & 1/4 & 1/5 & 1 & 6 & 6 \\ 1/3 & 1/5 & 1/6 & 1/6 & 1 & 1 \\ 1/3 & 1/5 & 1/6 & 1/6 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C3-2
$$\begin{pmatrix} 1 & 1/2 & 1/3 & 1/4 & 1/4 & 1/4 \\ 2 & 1 & 1/2 & 1/3 & 1/3 & 1/3 \\ 3 & 2 & 1 & 1/2 & 1 & 1 \\ 4 & 3 & 2 & 1 & 2 & 2 \\ 4 & 3 & 1 & 1/2 & 1 & 1 \\ 4 & 3 & 1 & 1/2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C3-3
$$\begin{pmatrix} 1 & 2 & 3 & 4 & 4 & 4 \\ 1/2 & 1 & 3 & 3 & 3 & 3 \\ 1/3 & 1/3 & 1 & 1 & 2 & 2 \\ 1/4 & 1/3 & 1 & 1 & 2 & 2 \\ 1/4 & 1/3 & 1/2 & 1/2 & 1 & 1 \\ 1/4 & 1/3 & 1/2 & 1/2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C3-4
$$\begin{pmatrix} 1 & 1/3 & 1/4 & 1/4 & 1/5 & 1/5 \\ 3 & 1 & 1/3 & 1/3 & 1/4 & 1/4 \\ 4 & 3 & 1 & 1/2 & 1/3 & 1/3 \\ 4 & 3 & 2 & 1 & 1/2 & 1/2 \\ 5 & 4 & 3 & 2 & 1 & 1 \\ 5 & 4 & 3 & 2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C4-1
$$\begin{pmatrix} 1 & 3 & 4 & 5 & 5 & 5 \\ 1/3 & 1 & 3 & 4 & 4 & 4 \\ 1/4 & 1/3 & 1 & 2 & 3 & 3 \\ 1/5 & 1/4 & 1/2 & 1 & 2 & 2 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 & 1 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C4-2
$$\begin{pmatrix} 1 & 2 & 4 & 4 & 5 & 5 \\ 1/2 & 1 & 3 & 3 & 4 & 4 \\ 1/4 & 1/3 & 1 & 2 & 3 & 3 \\ 1/4 & 1/3 & 1/2 & 1 & 2 & 2 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 & 1 \\ 1/5 & 1/4 & 1/3 & 1/2 & 1 & 1 \end{pmatrix}$$

A1,A2,A3,A4,A5,A6 w.r.t. C4-3
$$\begin{pmatrix} 1 & 1/2 & 1/3 & 1/4 & 1/5 & 1/5 \\ 2 & 1 & 1/2 & 1/3 & 1/4 & 1/4 \\ 3 & 2 & 1 & 1/2 & 1/3 & 1/3 \\ 4 & 3 & 2 & 1 & 1/2 & 1/2 \\ 4 & 4 & 3 & 2 & 1 & 1 \\ 4 & 4 & 3 & 2 & 1 & 1 \end{pmatrix}$$

alternative A6 with a rating equal to one of the five existing suppliers is evaluated. The test results have shown no change in the suppliers' ranking, the outranking is $A1 \succ A2 \succ A3 \succ A4 \succ A5 \succ A6$. All of these show that the MMAHP method has the property of preserving rank. However, when the original AHP is applied to the above supplier selection, the ranking of the five suppliers is $A1 \succ A2 \succ A5 \succ A3 \succ A4$. When adding a supplier with the same ranking number as one of the original suppliers, the order of preferences becomes $A1 \succ A2 \succ A3 \succ A4 \succ A5 \succ A6$. In this case, what is the fourth supplier A_3 becomes the third one, which is not expected in the supplier selection problem. This reversal of suppliers is known as ranking reversal.

Sub-criteria	Suppliers A1	A2	A3	A4	A5	A6
Quality	5.9235	3.9572	2.6672	1.8493	1.0000	1.0000
Price	7.2398	4.2339	2.3762	1.6475	1.0000	1.0000
Cost	1.0000	1.5874	2.7495	2.7495	4.8990	4.8990
Financial status	1.0000	1.7321	1.9442	2.9417	3.3019	3.3019
Quality certification	4.3645	3.1473	1.6654	1.0492	1.0000	1.0000
Social status	8.8068	5.1193	3.5255	2.2649	1.0000	1.0000
Geographical position	1.0000	1.3867	2.9417	3.7063	4.3644	4.3644
Business implementation capacity	5.5479	7.3833	5.0302	2.6207	1.0000	1.0000
Development and innovation	1.0000	1.5565	3.2377	5.7690	3.6342	3.6342
Technical ability	5.1396	3.5328	1.6654	1.5874	1.0000	1.0000
Service level	1.0000	1.7100	3.0468	4.3943	7.2398	7.2398
Green degree level	7.5141	4.4418	2.3762	1.5131	1.0000	1.0000
Resources recycling ability	6.7667	4.5299	2.3762	1.6475	1.0000	1.0000
Energy utilization ability	1.0000	1.8295	2.4183	3.9149	6.2145	6.2145

Table VIII. Ratings of suppliers under various sub-criteria

Method	A1	A2	A3	A4	A5	A6	Ranking
MMAHP	3.1279	2.9442	2.4574	2.2013	1.7686	1.7686	$A1 \succ A2 \succ A3 \succ A4 \succ A5 \succ A6$
AHP	0.2586	0.1925	0.1462	0.1356	0.1335	0.1335	$A1 \succ A2 \succ A3 \succ A4 \succ A5 \succ A6$

Table IX. The compromise solutions by different methods

5. Conclusion and future work

Environmental problems have attracted more and more attention from scholars. In order to occupy the market share and pursue the enterprise perpetuity, the firms need to select the suppliers who implement green strategy as a key part in their entire supply chain management. A good green supplier selection approach can help firms decrease the environmental and legal risks and increase the market competitiveness. In this paper, a MMAHP based approach is presented to select the best green supplier. For another important issue about rank reversal in the traditional AHP, the MMAHP has the property of preserving rank. Finally, the MMAHP is implemented with a numerical example in an automobile manufacturing firm. We also make a comparison with the result of the traditional AHP. The obtained results show that the order of green suppliers using the MMAHP does not change and maintains its original relative ratio when adding a supplier, while the rank of suppliers obtained by the traditional AHP is changed. Thus, the MMAHP contributes to helping researchers to choose more effective method for green supplier selection. In the future, we will extend the MMAHP to fuzzy environment or other domains, such as the evaluation value is fuzzy number, hesitant fuzzy number, etc.

References

Awasthi, A., Chauhan, S.S. and Goyal, S.K. (2010), "A fuzzy multicriteria approach for evaluating environmental performance of suppliers", *International Journal of Production Economics*, Vol. 126 No. 2, pp. 370-378.

Beikkhakhian, Y., Javanmardi, M., Karbasian, M. and Khayambashi, B. (2014), "The application of ISM model in evaluating agile suppliers selection criteria and ranking suppliers using fuzzy TOPSIS-AHP methods", *Expert Systems with Applications*, Vol. 42 Nos 15-16, pp. 6224-6236.

Buyukozkan, G. and Cifci, G. (2012), "A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers", *Expert Systems with Applications*, Vol. 39 No. 3, pp. 3000-3011.

Cárdenas-Barrón, L.E., González-Velarde, J.L. and Treviño-Garza, G. (2015), "A new appraoch to solve the multi-product multi-period inventory lot sizing with supplier selection problem", *Computers & Operations Research*, Vol. 64, pp. 225-232.

Chan, F.T.S. and Kumar, N. (2007), "Global supplier development considering risk factors using fuzzy extended AHP-based approach", *Omega-International Journal of Management Science*, Vol. 35 No. 4, pp. 417-431.

Chen, H.H. (2015), "A group selection approach to supplier collaborative configuration problems with correlation of experts and attributes", *International Journal of Computational Intelligence Systems*, Vol. 8 No. 6, pp. 1017-1026.

Deng, X., Hu, Y., Deng, Y. and Mahadevan, S. (2014), "Supplier selection using AHP methodology extended by D numbers", *Expert Systems with Applications*, Vol. 41 No. 1, pp. 156-167.

Diabat, A. and Govindan, K. (2011), "An analysis of the drivers affecting the implementation of green supply chain management", *Resources, Conservation and Recycling*, Vol. 55 No. 6, pp. 659-667.

Freeman, J. and Chen, T. (2015), "Green supplier selection using an AHP-entropy-TOPSIS framework", *Supply Chain Management-An International Journal*, Vol. 20 No. 3, pp. 327-340.

Fu, X., Zhu, Q. and Sarkis, J. (2012), "Evaluating green supplier development programs at a telecommunications systems provider", *International Journal of Production Economics*, Vol. 140 No. 1, pp. 357-367.

Geng, X.L. and Liu, Q.M. (2015), "A hybrid service supplier selection approach based on variable precision rough set and VIKOR for developing product service system", *International Journal of Computer Integrated Manufacturing*, Vol. 28 No. 10, pp. 1063-1076.

Hashemi, S.H., Karimi, A. and Tavana, M. (2015), "An integrated green supplier selection approach with analytic network process and improved Grey relational analysis", *International Journal of Production Economics*, Vol. 159, pp. 178-191.

Hou, F.J. (2011), "A Semiring-based study of judgment matrices: properties and models", *Information Sciences*, Vol. 181 No. 11, pp. 2166-2176.

Hou, F.J. (2012), "Rank preserved aggregation rules and application to reliability allocation", *Communications in Statistics-Theory and Methods*, Vol. 41 No. 21, pp. 3831-3845.

Hou, F.J. (2014a), "A semiring-based hierarchical decision model and application", *Journal of Data Analysis and Operations Research*, Vol. 1 No. 1, pp. 25-33.

Hou, F.J. (2014b), "A multiplicative alo-group based hierarchical decision model and application", *Communications in Statistics – Simulation and Computation*, pp. 1-28. doi: 10.1080/03610918.2014.930898.

Hruska, R., Prusa, P. and Babic, D. (2014), "The use of AHP method for selection of supplier", *Transport*, Vol. 29 No. 2, pp. 195-203.

Hsu, C.-W. and Hu, A.H. (2009), "Applying hazardous substance management to supplier selection using analytic network process", *Journal of Cleaner Production*, Vol. 17 No. 2, pp. 255-264.

Hsu, C.-W., Kuo, T.-C., Chen, S.-H. and Hu, A.H. (2013), "Using DEMATEL to develop a carbon management model of supplier selection in green supply chain management", *Journal of Cleaner Production*, Vol. 56, pp. 164-172.

Huang, S.H. and Keskar, H. (2007), "Comprehensive and configurable metrics for supplier selection", *International Journal of Production Economics*, Vol. 105 No. 2, pp. 510-523.

Kainuma, Y. and Tawara, N. (2006), "A multiple attribute utility theory approach to lean and green supply chain management", *International Journal of Production Economics*, Vol. 101 No. 1, pp. 99-108.

Kannan, G., Haq, A.N., Sasikumar, P. and Arunachalam, S. (2008), "Analysis and selection of green suppliers using interpretative structural modelling and analytic hierarchy process", *International Journal of Management and Decision Making*, Vol. 9 No. 2, pp. 163-182.

Karsak, E.E. and Dursun, M. (2015), "An integrated fuzzy MCDM approach for supplier evaluation and selection", *Computers & Industrial Engineering*, Vol. 82, pp. 82-93.

Kar, A.K. (2015), "A hybrid group decision support system for supplier selection using analytic hierarchy process, fuzzy set theory and neural network", *Journal of Computational Science*, Vol. 6, pp. 23-33.

Lee, A.H.I., Kang, H.Y., Hsu, C.F. and Hung, H.C. (2009), "A green supplier selection model for high-tech industry", *Expert Systems with Applications*, Vol. 36 No. 4, pp. 7917-7927.

Lu, L.Y., Wu, C. and Kuo, T.C. (2007), "Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis", *International Journal of Production Research*, Vol. 45 Nos 18-19, pp. 4317-4331.

Memon, M.S., Lee, Y.H. and Mari, S.I. (2015), "Group multi-criteria supplier selection using combined grey systems theory and uncertainty theory", *Expert Systems with Applications*, Vol. 42 No. 21, pp. 7951-7959.

Min, H. and Galle, W.P. (1997), "Green purchasing strategies: trends and implications", *International Journal of Purchasing and Materials Management*, Vol. 33 No. 2, pp. 10-17.

Moghaddam, K.S. (2015), "Fuzzy multi-objective model for supplier selection and order allocation in reverse logistics systems under supply and demand uncertainty", *Expert Systems with Applications*, Vol. 42 Nos 15-16, pp. 6237-6254.

Noci, G. (1997), "Designing 'green'vendor rating systems for the assessment of a supplier's environmental performance", *European Journal of Purchasing & Supply Management*, Vol. 3 No. 2, pp. 103-114.

Pitchipoo, P., Venkumar, P. and Rajakarunakaran, S. (2015), "Grey decision model for supplier evaluation and selection in process industry: a comparative perspective", *International Jouranl of Advanced Manufacturing Technology*, Vol. 76 Nos 9-12, pp. 2059-2069.

Rao, P. (2002), "Greening the supply chain: a new initiative in South East Asia", *International Journal of Operations & Production Management*, Vol. 22 Nos 5-6, pp. 632-655.

Rao, P. and Holt, D. (2005), "Do green supply chains lead to competitiveness and economic performance?", *International Journal of Operations & Production Management*, Vol. 25 No. 9, pp. 898-916.

Sarkis, J. (2003), "A strategic decision framework for green supply chain management", *Journal of Cleaner Production*, Vol. 11 No. 4, pp. 397-409.

Sevkli, M., Koh, S.C.L., Zaim, S., Demirbag, M. and Tatoglu, E. (2007), "An application of data envelopment analytic hierarchy process for supplier selection: a case study of BEKO in Turkey", *International Journal of Production Research*, Vol. 45 No. 9, pp. 1973-2003.

Simic, D., Svircevic, V. and Simic, S. (2015), "A hybrid evolutionary model for supplier assessment andselection ininbound logistics", *Journal of Applied Logic*, Vol. 13 No. 2, pp. 138-147.

Tsai, W.H. and Hung, S.J. (2009), "A fuzzy goal programming approach for green supply chain optimisation under activity-based costing and performance evaluation with a value-chain structure", *International Journal of Production Research*, Vol. 47 No. 18, pp. 4991-5017.

Tseng, M.-L. and Chiu, A.S.F. (2013), "Evaluating firm's green supply chain management in linguistic preferences", *Journal of Cleaner Production*, Vol. 40, pp. 22-31.

Van Hoek, R.I. (1999), "From reversed logistics to green supply chains", *Supply Chain Management: An International Journal*, Vol. 4 No. 3, pp. 129-135.

Walton, S.V., Handfield, R.B. and Melnyk, S.A. (1998), "The green supply chain: integrating suppliers into environmental management processes", *International Journal of Purchasing and Materials Management*, Vol. 34 No. 1, pp. 2-11.

Wu, D. (2009), "Supplier selection: a hybrid model using DEA, decision tree and neural network", *Expert Systems with Applications*, Vol. 36 No. 5, pp. 9105-9112.

You, X.Y., You, J.X., Liu, H.C. and Zhen, L. (2015), "Group multi-criteria supplier selection using an extended VIKOR method with interval 2-tuple linguistic information", *Expert Systems with Applications*, Vol. 42 No. 4, pp. 1906-1916.

Zhu, Q.H., Sarkis, J. and Geng, Y. (2005), "Green supply chain management in China: pressures, practices and performance", *International Journal of Operations & Production Management*, Vol. 25 Nos 5-6, pp. 449-468.

Further reading

Kannan, G. and Vinay, V. (2008), "Multi-criteria decision making for the selection of CAD/CAM system", *International Journal on Interactive Design and Manufacturing*, Vol. 2 No. 3, pp. 151-159.

Lee, A.H. (2009), "A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks", *Expert Systems with Applications*, Vol. 36 No. 2, pp. 2879-2893.

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1. Aleksander Banasik, Jacqueline M. Bloemhof-Ruwaard, Argyris Kanellopoulos, G. D. H. Claassen, Jack G. A. J. van der Vorst. 2016. Multi-criteria decision making approaches for green supply chains: a review. *Flexible Services and Manufacturing Journal* . [CrossRef]
2. Jafar Rezaei, Thomas Nispeling, Joseph Sarkis, Lori Tavasszy. 2016. A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. *Journal of Cleaner Production* **135**, 577-588. [CrossRef]
3. Arash Shahryari Nia, Laya Olfat, Ahmad Esmaeili, Reza Rostamzadeh, Jurgita Antuchevičienė. 2016. Using fuzzy Choquet Integral operator for supplier selection with environmental considerations. *Journal of Business Economics and Management* **17**:4, 503-526. [CrossRef]