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Prioritizing Green Supplier Selection Criteria using Fuzzy Analytical Network Process

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Abstract

In spite of the vast amount of studies on green supplier selection and related methods and approaches, the evaluation of green supply chain performance indicators aligned with classic measures is less investigated. Therefore, this research attempted to provide an integrated step by step procedure to consider both classical and green key performance indicators within the supplier selection framework. A literature survey was conducted and measures for assessing the green suppliers were extracted. Nominal Group Technique (NGT) is deployed to extract the most critical performance measures. Ten performance measures were selected as a substitute for green supplier selection. A Fuzzy Analytical Network Process (FANP) was then deployed to weight the extracted measures and determine their importance level.

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Keywords: Supplier Selection, Green Supply Chain Management, Fuzzy Analytical Hierarchy Process, NGT

1. Introduction

With the advent of industrialization, green supply chain management can be defined as a strategy for all supply chain members to attain more value. Today's competitive markets have forced companies to focus on environmental issues aligned with other critical factors (e.g. Cost, quality, service level and etc.) to increase the supply chain surplus. Although the concepts of green supplier selection have been investigated [1-3], few attempts have been made to provide green supplier selection measures adjacent to classical measures for electrical industries. In this context, identifying, weighting, and using the fit measures to efficiently and effectively assess and appraise suppliers is a challenge for many scholars, practitioners, and managers [4-8].

While green supply chain performance measures should be considered in the supplier selection process, they are less investigated in the literature. This is partly due to the intrinsic complexities connected with green measures aligned with neglecting environmental issues in many developing countries. Additionally, green supply chain performance measures are not enough for the aim of supplier evaluation and should be integrated with other classic measures (e.g. Cost, quality, service level and etc.). However, integrating performance measures to provide a mixed (classic and green) supplier evaluation framework for electronic and electrical industries can be valuable.

The scope of this study is limited to small and medium enterprises (SMEs) in the Iranian electronic industry. This paper provides a step by step procedure for green supplier selection using fuzzy analytic hierarchy process.

2. Literature Review

Since last two decades, many companies purchases are not only basic supplies and raw materials, but also due to stress on strategic partnering, strategic alliances, outsourcing and relationship marketing, complex fabricated components with very high value-added content and services have been added to their purchases. Therefore, in the professional industrial, evaluation of suppliers or vendor selection has became a critical factor in industrial buying process [9, 10]. However, selecting an appropriate vendor has been basically being a non-trivial task for as much as multiple criteria need to be

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wisely prioritized. To do so, most of the decision makers empirically select vendors and since these approaches are subjective, several studies have demonstrated their weakness [11, 12].

Essentially, supplier selection is a decision process with the aim of reducing the initial set of potential suppliers to the final choices [5, 13]. Decisions are based on evaluation of suppliers on multiple quantitative as well as qualitative criteria.

Depending on the situation at hand, selecting suppliers may require searching for new suppliers or choosing suppliers from the existing pool of suppliers. In any case, there is a degree of uncertainty in the decision process, which is caused by subjective evaluation of qualitative or quantitative criteria, by multiple decision makers, with no previous data to rely on [5, 14-17].

During the last two decades, environmental issues have become a major source of consideration in purchasing [18-20]. Today, both the public and private sector are under increasing pressure for their purchasing policies to consider the environmental aspects. The environmental concern of purchasing policies is known as green purchasing or green procurement. Therefore, enterprises providing environmentally friendly products and services have extra credit and recognition for their efforts. This will leads to motivation of other firms to align their effort to deliver environmentally friendly products and services. Consequently, the whole perspective of green market is growing, and green purchasing is regarded as a contribution to sustainable development. Prime environmental consideration in the research work have begun during the 1980s and 1990s [21, 22].

Therefore this paper is an attempt to integrate classic supply chain performance measures (e.g. cost, quality, service level and etc.) with green supply chain performance measures considering the characteristics of electrical industries. It should be noted that the current supplier selection approaches are based on the expert's opinion that are subjected to validity issues. Hence, a precise mathematical method can consider the various weights of the expert's opinion into an integrated supplier selection approach. Finally, real world's decisions are made in fuzzy environment and this can justify the application of fuzzy logic through the decision making procedure.

This paper proposes a fuzzy analytic hierarchy process model for prioritizing green supplier selection measures to help managers and researchers to select suppliers with consideration of green supply chain performance measures (GSCPM).

3. Methodology

In the first phase of this research, a literature review was conducted to extract the green supplier selection criteria aligned with essential classic criteria of supplier selection. Nominal Group Technique (NGT) was then deployed for the most critical criteria of green supplier selection. Experts were asked to consider both classical and green aspects aligned with the characteristics of electrical industries during the final decision on supplier selection criteria. Accordingly, the degree of interdependent relationships between different criteria was determined by the expert group using NGT. The interdependence level will affect the ultimate weights of criteria. The interdependency between the criteria were determined and ultimately the weight of criteria was computed using FANP method. A comprehensive checklist was designed based on the criteria which can be used for supplier evaluation. Finally, based on the score achieved, the supplier may be accepted or rejected.

3.1. Determining the Criteria

A literature review survey was conducted to extract both classic and green performance measures. NGT was then deployed for the most critical criteria. Experts were also asked to consider industry's specification within the decision making process. The result of NGT is shown in Table 1.

3.2. Interdependency between Criteria

The interaction between each pair of these criteria is not considered in the first instance to abridge the process and avoid any misunderstandings. Subsequently, the effect of interdependency among different criteria should be known to find the accurate link among the criteria in ANP. This study has deployed NGT for determining the criterion interdependency level. Expert group contains experienced managers from electrical industries aligned with academic people.

Table 1. Green Supplier Selection Key Performance Indicators (GSSKPIs)

No	Indicator	Measure	Reference Example
1	C1	Price	[7, 23-25]
2	C2	Quality	[23, 26, 27]
3	C3	Reputation	[4, 25, 28, 29]
4	C4	Service and delivery	[5, 25, 30, 31]
5	C5	Distance	[32-34]
6	C6	Use of Green Materials	[3, 19, 35]
7	C7	Air Emission Level	[1, 36-38]
8	C8	Waste Level	[1, 3, 39, 40]
9	C9	Energy Efficiency	[3, 33, 41, 42]
10	C10	Green Design Capability	[1, 43, 44]

3.3. Weighting the Green Supplier Selection Criteria

Each expert assigns a proper weight to each criteria which is used for the FANP method. Interdependency level is also determined to address the relative importance of the criteria. ANP is developed to make priorities for alternatives devoid of making assumptions about a unidirectional hierarchy relationship between decision levels [45, 46]. The relative importance of a given factor is calculated on a ratio scale, which is similar to the analytical hierarchy process (AHP) method. The matrix manipulation used in this study uses the concept of Saaty and Takizawa [47] instead of Saaty's original supermatrix to simplify the understanding.

One of the proper characteristics of ANP is consideration of explicit interactions in the process. This can increase the accuracy of supplier selection process [48]. Without assuming the criteria interdependency, experts were asked to assess all proposed criteria or make the pairwise comparison. Despite the fact that experts use their academic and practical abilities to make the comparison task, the disability of AHP/ANP to reflect the way a human thinks should be also considered. Fuzzy sets are more compatible with linguistic terms and ambiguities used by human beings [49]. Consequently, It is proper to deploy fuzzy numbers so as to make real world decisions. Geometric mean precisely stands for the consensus of experts and is used by many scholars in the available literature [46]. Each number in the pairwise comparison matrix shows the personal view of decision makers and is an ambiguous concept. Using fuzzy numbers is the best approach to unite divided expert comments. Following presents the essential equations.

$$M_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right) \quad (1)$$

$$l_{ij} = \min\left(B_{ijk}\right) \quad (2)$$

$$m_{ij} = \sqrt[n]{\prod_{k=1}^{n} B_{ijk}} \quad (3)$$

$$u_{ij} = max\left(B_{ijk}\right) \quad (4)$$

Where Bijk denotes kth expert score for the comparative importance of two criteria Ci – Cj. The algebraic operations for each two triangular fuzzy numbers M1and M2 can be stated as follow;

$$M_1 + M_2 = \left(l_1 + l_2, m_1 + m_2, u_1 + u_2\right) \quad (5)$$

$$M_1 * M_2 = \left(l_1 * l_2, m_1 * m_2, u_1 * u_2\right) \quad (6)$$

$$M_1^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right), M_2^{-1} = \left(\frac{1}{u_2}, \frac{1}{m_2}, \frac{1}{l_2}\right) \quad (7)$$

Note that multiplying two triangular fuzzy numbers or the convex triangular-fuzzy number is no longer a triangular fuzzy number. These equations are only show an estimation for real two triangular fuzzy numbers multiplication or the convex triangular fuzzy number ones. The following equation is applied in EA method for each column of pairwise matrix in order to identify triangular number Sk as well as the fuzzy combined value for the ith entity.

$$S_k = \sum_{j=1}^{n} M_{kj} * \left[\sum_{i=1}^{m}\sum_{j=1}^{n} M_{ij}\right]^{-1} \quad (8)$$

After Sk values being calculated, possibility degree for every two Sk should be determined. Subsequently, if M1 and M2 are two triangular fuzzy numbers, possibility degree for M1 over M2 is calculated as below (also written as M1>= M2):

$$\begin{cases} V\left(M_1 \geq M_2\right) = 1 & \text{if } M_1 \geq M_2 \\ V\left(M_1 \geq M_2\right) = 0 & \text{if } L_1 \geq U_2 \\ V\left(M_1 \geq M_2\right) = hgt\left(M_1 \cap M_2\right) & \text{otherwise} \end{cases} \quad (9)$$

$$hgt\left(M1 \cap M2\right) = \frac{u_1 \_ l_2}{\left(u_1 - l_2\right) + \left(m_2 - m_1\right)} \quad (10)$$

According Baldwin and Guild, the Baas-Kwakernaak method is inappropriate choices due to the lack of the discriminatory power. They also criticized the work of Dubois and Prade for not including all the available information present in membership functions [50-52]. In this study, we face to large scale of a triangular number from the remain k number of the triangular number which obtained from equation (9):

$$V\left(M_1 \geq M_2 \dots M_k\right) = V\left(M_1 \geq M_2\right), \dots, V\left(M_1 \geq M_k\right) \quad (11)$$

In order to calculate the weights of indices in pairwise matrix, the following steps are considered:

$$W\left(x_i\right) = Min\left\{V\left(S_i \geq S_k\right)\right\} \quad k = 1,2,3,\dots,n \;\; k \neq i \quad (12)$$

As a result, the weight vectors are defined as:

$$w'(X_i) = [W'(C_1), W'(C_2), W'(C_n)]^T \quad (13)$$

Which are the same values as fuzzy AHP non-normal coefficients. Equation (12) results to normal values of obtained results of equation (11). We called the normal values as W.

$$W_i = \frac{w_i'}{\sum w_i'} \quad (14)$$

Afterward, the correlations effect among criteria is determined. Pairwise comparisons are applied in order to measure the mutual impact of criteria against each other by the group members. Pairwise comparisons matrices are provided for each criterion. In provided pairwise comparison matrices, the relative impacts of interdependent criteria relationships are required. The main specific normal vectors of these matrices are considered as the column arrays in matrix B regarding to the weights correlations. In matrix B, the zeroes value for the weights show specific vectors which mean the criteria have no correlation with another corresponding ones. To combine the two previous steps, we applied equation (16) to calculate the comparative correlation of the criteria. Combination in this process means implementing of coefficient interdependency weight matrix over the results of the fuzzy AHP process.

$$W_c = B.W \quad (15)$$

3.4. Checklist development and Auditing

The assessment checklist is designed based on proposed criteria. For example, indexes are identified for each criterion and are assigned proper marks to calculate the value of each criterion. The audit is an independent evaluation approach with a sight to settle on whether the supplier satisfies the reliable conditions for each checklist criterion or supplier is efficiently adapted to considered criteria and has the competency conformance with the criteria. The audit reference scheme has to obey with the rating schedule for the supplier assessment. Table 2 represents the principle of criteria rating.

Table 1: Criterion rating values

Criterion Rating	Level of conformance	Observation
3	Satisfactory	The criterion audited is taken into account; the auditor detects no deviation relative to the reference file.
2	Acceptable	The criterion is taken into account; the auditor detects small deviations relative to the reference file.
1	Inadequate	The criterion audited is taken into account; the auditor detects major deviations relative to the reference file.
0	Unsatisfactory	The criterion or a part of the criterion is not taken into account.

4. Calculating the Total Score of Supplier

The overall rating for each criterion summarized the process of audited items. The conformance criterion is based on the total quantity of index for each criterion which are taken into account. Conformance criterion is the sum of index result rate for each criterion divided by sum of the index rate for each criterion. Then, Total score is calculated by multiplying the conformance criterion value by its related weights. Based on the total score, supplier categorized into one of three possible situations. It is shown in Table 3

Table 2: guideline for decision maker

Rating	Result	Observations
T.S ≥80% and score of criteria was more than 50%	Acceptable Level A	The supplier is eligible to select.
70% ≤T.S < 80% and score of criteria was more than 50%	Under supervision Level B	The supplier is not good but can be selected in order to make the primary contract. The supplier has to evolve to status "80% ≤T.S" within a period of 12 months maximum.
T.S < 70% or one score of criteria was less than 50%	Not acceptable Level C	The supplier reject from the panel.

TS= Total Score

5. Result and Discussion

Referring to Table 1, price, quality, reputation, service and delivery, distance, use of green materials, air emission level, waste level, energy efficiency and green design capability were selected as the main criteria for the aim of green supplier selection. Interdependency of criteria should be identified. The precise relationship in a network structure of ANP should be known in order to correctly demonstrate the criteria interdependency. NGT is used to achieve the relationships between criteria. The result is shown as follows:

I. Price may be influenced by the quality of products, use of green materials, energy efficiency and green design capability (C1and C2, C6, C9, C10)

II. Quality may be influenced by use of green materials (C2 and C6)

III. Reputation is affected by quality and service and delivery (C3 and C2, C4)

IV. Service and delivery may be affected by distance (C4 and C5)

V. Air emission level, waste level, energy efficiency level and green design capability may be influenced by the use of green materials (C7, C8, C9, C10 and C6).Figure 1 shows the interdependency relationship between different criteria. For example, the arrow that leaves from C2 and feeds into C1 demonstrates that the criterion C2 has an impact on criteria C1.

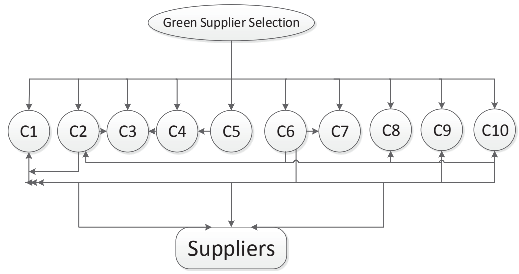

Figure 1: The interdependent relationship between selected criteria

The next step is to compute the weight of each criterion. In this project, a team of four experts in the case study were selected. They were asked to evaluate all criteria based on the pairwise method despite the assumption on the interdependence between them. Having the related calculations using equations 1-15, following shows the final ranking of green supplier selection criteria using FANP.

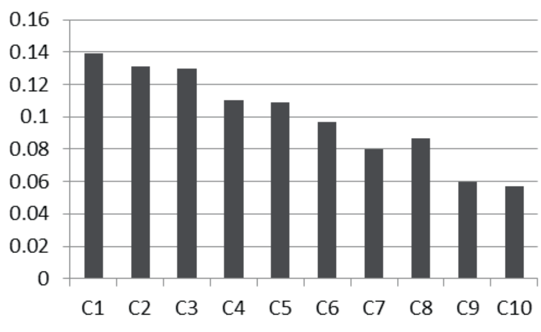

Figure 2: Final ranking of green supplier selection criteria using FANP

6. Creating a Checklist According to Criteria

Evaluation checklist is an instrument designed to audit supplier. An evaluation survey containing questions covering all these 10 measures can be designed to assess suppliers. The auditor should have the option to explain his/her choices and express his/her opinions about a specific measure. The total score should be calculated according to following equations.

$$\text{Conformance criterion} = \frac{\text{sum of index result rate for each criterion}}{\text{sum of index rate for each criterion}} \quad (16)$$

$$\text{Total score} = \text{value of conformance criterion} * \text{related weight} \quad (17)$$

Potential suppliers are evaluated based on the score for each criterion and this should not be less than 50% and total score should not be less than 80%. If the total score is between 70% and 80% and the score for each criterion is not less than 50%, the supplier can be accepted with further supervision. The supplier has to evolve into status "80%⩽ T.S" within a maximum period of 12 months. If the T.S < 70% or one score of criteria is less than 50% the supplier will be rejected from the assessment [53].

7. Conclusion

Supplier selection is a multi-criteria decision making process. The methodology used in this study is both qualitative and quantitative and uses NGT to extract the most important green supplier selection key performance indicators (GSSKPIs) aligned with addressing a FANP to rank them. Methodology used in this study is flexible to be used for different managerial decisions (e.g. assigning a higher cost to classic measures or green measures) to evaluate suppliers.

The main issue covered in this study was to find and rank the most important measures for the aim of green supplier selection. A literature survey was conducted and ten measures were extracted. The main contribution of this study is to integrate both classic and green key performance indicators for the aim of supplier selection. Ranking these measures using expert's opinion can make the supplier selection framework specific for electrical industries. Future researches encourage considering social criteria in conjunction with measures applied in this study.

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