An Evaluation Model for Green and Low-Carbon Suppliers

Amy H. I. Lee[1,2,3], He-Yan Kang[4], Chun Yu Lin[2] and Hsin Wei Wu[3]
[1]*Department of Technology Management, Chung Hua University, Hsinchu, Taiwan, ROC*
[2]*Ph. D. Program of Technology Management- Industrial Management, Chung Hua University, Hsinchu, Taiwan, ROC*
[3]*Department of Industrial Management, Chung Hua University, Hsinchu, Taiwan, ROC*
[4]*Department of Industrial Engineering and Management, National Chin-Yi University of Technology, Taichung, Taiwan, ROC*

Keywords: Suppliers, Low-Carbon, Fuzzy Analytic Network Process, Fuzzy Set.

Abstract: Under a conventional supplier evaluation, cost, on-time delivery and quality are treated as the most important factors. However, in today's increasingly environmental conscious market with growing demands of green products, more and more firms are aiming to manufacture green products to reduce the damage to the environment and to limit the use of energy and other resources at any stage of its life, including raw materials, manufacture, use, and disposal. Thus, a firm needs to select the right suppliers that not only can satisfy the basic requirements, such as cost and quality, but also can provide green and low-carbon materials. The goal of this research is to construct a green and low-carbon supplier evaluation model. The criteria to evaluate green and low-carbon suppliers are analyzed first, and the most important ones are selected. Fuzzy analytic network process (FANP) model is constructed to evaluate various aspects of suppliers. By applying the model, the manufacturer can find the most suitable suppliers for cooperation. Goal programming (GP) is applied next to allocate the most appropriate amount of orders to each of the selected suppliers.

1 INTRODUCTION

Firms today have entered a slim profit-margin era due to global competition and fast-changing technology. In order to lower costs, raise profit and attain core technology and competitiveness in the supply chain, firms often needs to switch from arm's length purchasing transactions into some kind of buyer-supplier partnership, such as contractual purchase and cooperative relationship. The selection of suitable suppliers for partnership is one of the most important steps in creating a successful supply chain and in attaining reasonable profits for a firm (Todeva and Knoke, 2005). In addition, to confront the global warming problem and the increase in environmental consciousness, many countries have devised various environmental protection policies. For instance, with the Energy-using Product Directive (2005/32/EC), the European Commission has been addressing energy-using and energy-related products which have a considerable impact on the energy consumption in the market (Friedman, 2008). International environmental issues have also built up some technical non-tariff barriers to trade. Therefore, the communities are paying attention to the environmental protection of the enterprises, and international companies and original design manufacturing (ODM) manufacturers need to start promoting green products actively. The purpose of this study aims to incorporate the concept of carbon reduction and green environmental considerations in designing a supplier selection model. The fuzzy analytic network process (FANP) model is constructed to calculate the weights of performance criteria and to obtain the overall performance of suppliers. By applying goal programming (GP), the order allocation to the suppliers can be determined. The model can generate a list of criteria which are the most important for firms to assess the performance of suppliers and to give directions for suppliers to improve their performances.

The rest of the paper is organized as follows. In the next section, the methodologies are introduced. In section 3, a FANP/GP model is constructed. A case study is presented next in section 4. In the last section, some conclusion remarks and future research directions are made.

Lee A., Kang H., Lin C. and Wu H..
An Evaluation Model for Green and Low-Carbon Suppliers.
DOI: 10.5220/0004030406040608
In *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics* (OMDM-2012), pages 604-608
ISBN: 978-989-8565-22-8

2 METHODOLOGIES

2.1 Fuzzy Analytic Network Process (Fanp)

Because analytic network process (ANP) can consider the interrelationships among elements in a problem setting, the use of the ANP instead of analytic hierarchy process (AHP) has increased substantially in recent years. To consider the fuzziness and vagueness in the decision making process, fuzzy set theory can be incorporated into the ANP, so called FANP. An example of the procedures for the FANP is as follows (Kang, Lee and Yang, 2010; Lee, Wang and Lin, 2010):

1. Decompose the problem into a network.
2. Prepare a questionnaire based on the constructed network, and ask experts to fill out the questionnaire. The questionnaire will be prepared based on pairwise comparison with Saaty's nine point scales (Saaty, 1980). Experts are asked to fill out the questionnaire. Consistency index and consistency ratio for each comparison matrix are calculated to examine the consistency of each expert's judgment (Saaty, 1980). If the consistency test is not passed, the original values in the pairwise comparison matrix must be revised by the expert.
3. Aggregate the results of the experts' questionnaires. The scores of pairwise comparison are transformed into linguistic variables by the transformation concept. According to Buckley (1985) the fuzzy positive reciprocal matrix can be defined as:

$$\tilde{A}^k = \left[\tilde{a}_{ij}\right]^k \quad (1)$$

$\tilde{A}^k$: a positive reciprocal matrix of decision maker k;

$\tilde{a}_{ij}$: relative importance between decision elements i and j;

$\tilde{a}_{ij} = 1, \forall i = j$ and $\tilde{a}_{ij} = 1 / \tilde{a}_{ji}, \forall i, j = 1,2,\ldots\ldots,n$

If there are k experts $P_1, P_2\ldots, P_k$, every pairwise comparison between two criteria has k positive reciprocal triangular fuzzy numbers. Employ geometric average approach to aggregate multiple experts' responses, and the aggregate fuzzy positive reciprocal matrix is:

$$\tilde{A}^* = \left[\tilde{a}_{ij}{}^*\right] \quad (2)$$

where $\tilde{a}_{ij}{}^* = \left(\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \ldots\ldots \otimes \tilde{a}_{ij}^k\right)^{1/k}$

4. Defuzzy the synthetic triangular fuzzy numbers $\tilde{a}_{ij}{}^* = \left(x_{ij}, y_{ij}, z_{ij}\right)$ into crisp numbers. For instance, the center of gravity (COG) method can be applied.

$$a_{ij}{}^* = \left(x_{ij} + y_{ij} + z_{ij}\right) / 3, \forall i, j = 1,2,\ldots\ldots,n \quad (3)$$

5. Form pairwise comparison matrices using the defuzzificated values, and apply software, such as Super Decisions or Excel, to form an unweighted supermatrix. Next, form a weighted supermatrix to ensure column stochastic.
6. Calculate the limit supermatrix by taking the weighted supermatrix to $2q+1$ powers so that the supermatrix converges into a stable supermatrix. Obtain the priority weights of the alternatives from the limit supermatrix.

2.2 Goal Programming (GP)

Goal programming (GP) is useful in dealing with multi-criteria decision problems where the goals cannot simultaneously be optimized, and decision makers can consider several objectives together in finding a set of acceptable solutions and to obtain an optimal compromise (Lee, Kang and Chang, 2009). The purpose of GP is to minimize the deviations between the achievement of goals and their aspiration levels (Chang, 2007). GP has been applied in various studies. For example, an integrated AHP and preemptive goal programming methodology is developed by Wang, Huang and Dismukes (2004) to select the best set of multiple suppliers to satisfy capacity constraint.

The achievement function of GP is (Chang, 2007; Lee et al., 2009):

$$\text{Min } \sum_{i=1}^{n} w_i (d_i^+ + d_i^-) \quad (4)$$

$$\text{s.t. } f_i(X) - d_i^+ + d_i^- = \sum_{j=1}^{m} g_{ij} S_{ij}(B), \ i = 1,2,\ldots,n \quad (5)$$

$$d_i^+, d_i^- \geq 0, \ i = 1,2,\ldots,n \quad (6)$$

$$S_{ij}(B) \in U_i(x), \ i = 1,2,\ldots,n \quad (7)$$

$$X \in F \quad (F \text{ is a feasible set}) \quad (8)$$

where d_i is the deviation from the target value g_i; w_i represents the weight attached to the deviation; $d_i^+ = \max(0, f_i(X) - g_i)$ and $d_i^- = \max(0, g_i - f_i(X))$ are, respectively, over- and under-achievements of the ith goal; $S_{ij}(B)$

represents a function of binary serial number; and $U_i(x)$ is the function of resources limitations.

Based on the fuzzy theory, the highest possible value of membership function is 1 for something that is more/higher the better in the aspiration levels (Charnes and Cooper, 1961). To achieve the maximization of $g_{ij}S_{ij}(B)$, the flexible membership function goal with aspiration level 1 (i.e., the highest possible value of membership function) is (Chang, 2007):

$$\frac{g_{ij}S_{ij}(B)-g_{\min}}{g_{\max}-g_{\min}}-d_i^{+}+d_i^{-}=1 \tag{9}$$

where $g_{\max}$ and $g_{\min}$ are, respectively, the upper and lower bound of the right-hand side (i.e., aspiration levels) of equation (5).

For a simpler calculation, the fractional form of equation (9) is:

$$\frac{1}{\mathrm{L}_i}g_{ij}S_{ij}(B)-\frac{1}{\mathrm{L}_i}g_{\min}-d_i^{+}+d_i^{-}=1 \tag{10}$$

where $\mathrm{L}_i = g_{\max} - g_{\min}$.

For something that is less/lower the better in the aspiration levels, the similar idea of maximization of $g_{ij}S_{ij}(B)$ can be used to achieve the minimization of $g_{ij}S_{ij}(B)$. The flexible membership function goal with the aspiration level 1 (i.e., the lowest possible value of membership function) is (Chang, 2007):

$$\frac{g_{\max}-g_{ij}S_{ij}(B)}{g_{\max}-g_{\min}}-d_i^{+}+d_i^{-}=1 \tag{11}$$

where $g_{\max}$ and $g_{\min}$ are, respectively, the upper and lower bound of the right-hand side (i.e., aspiration levels) of equation (5).

The fractional form of equation (11) can be converted into a polynomial form:

$$\frac{1}{\mathrm{L}_i}g_{\max}-\frac{1}{\mathrm{L}_i}g_{ij}S_{ij}(B)-d_i^{+}+d_i^{-}=1 \tag{12}$$

3 AN INTEGRATED MODEL FOR FANP AND GP MODEL

The steps of the proposed FANP and GP model are summarized as follows:

Step 1. Define the green and low-carbon supplier evaluation problem, and construct an evaluation network with criteria, detailed criteria and alternatives.

Step 2. Prepare and distribute a questionnaire. A questionnaire with five linguistic terms, as shown in Table 1, is prepared based on the constructed network.

Table 1: Triangular fuzzy numbers.

Linguistic variable	Fuzzy number	Membership function of fuzzy number
Extremely strong	$\tilde{9}$	(9,9,9)
Intermediate	$\tilde{8}$	(7,8,9)
Very strong	$\tilde{7}$	(6,7,8)
Intermediate	$\tilde{6}$	(5,6,7)
Strong	$\tilde{5}$	(4,5,6)
Intermediate	$\tilde{4}$	(3,4,5)
Moderately strong	$\tilde{3}$	(2,3,4)
Intermediate	$\tilde{2}$	(1,2,3)
Equally strong	$\tilde{1}$	(1,1,1)

Step 3. Prepare pairwise comparison matrix. With pairwise comparison of criteria with respect to the overall objective, we can obtain a matrix ($\tilde{\mathrm{A}}_{\mathbf{1k}}$) for expert *k*:

$$\tilde{\mathrm{A}}_{1k}=\begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_i \\ C_j \\ \vdots \\ C_m \end{array}\begin{array}{c} \begin{array}{ccccccc} C_1 & C_2 & \cdots & C_i & C_j & \cdots & C_m \end{array} \\ \begin{bmatrix} 1 & \tilde{a}_{12k} & \cdots & \cdots & \cdots & \cdots & \tilde{a}_{1mk} \\ 1/\tilde{a}_{12k} & 1 & \cdots & \cdots & \cdots & \cdots & \tilde{a}_{2mk} \\ \vdots & \vdots & 1 & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & 1 & \tilde{a}_{ijk} & \cdots & \cdots \\ \vdots & \vdots & \vdots & 1/\tilde{a}_{ijk} & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & 1 & \cdots \\ 1/\tilde{a}_{1mk} & 1/\tilde{a}_{2mk} & \cdots & \cdots & \cdots & \cdots & 1 \end{bmatrix} \end{array} \tag{13}$$

where *m* is the number of criteria (C).

Step 4. Aggregate experts' opinions and build an aggregated fuzzy pairwise comparison matrix. Geometric average approach is employed to aggregate experts' responses and to obtain a synthetic triangular fuzzy number (Lee, 2009; Lee et al., 2009):

$$\tilde{a}_{ij}=\left(\tilde{a}_{ij1}\otimes\tilde{a}_{ij2}\otimes\ldots\ldots\otimes\tilde{a}_{ijk}\right)^{1/k} \tag{14}$$

where $\tilde{a}_{ijk}=\left(l_{ijk},t_{ijk},u_{ijk}\right)$

The fuzzy aggregated pairwise comparison matrix is:

$$\tilde{\mathbf{A}}_1 = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \cdots & \cdots & \cdots & \tilde{a}_{ij} \\ 1/\tilde{a}_{12} & 1 & \cdots & \cdots & \cdots & \cdots & \tilde{a}_{2j} \\ \vdots & \vdots & 1 & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & 1 & \tilde{a}_{ij} & \cdots & \cdots \\ \vdots & \vdots & \vdots & 1/\tilde{a}_{ij} & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & 1 & \cdots \\ 1/\tilde{a}_{1j} & 1/\tilde{a}_{2j} & \cdots & \cdots & \cdots & \cdots & 1 \end{bmatrix} \quad (15)$$

where $\tilde{a}_{ij} = (l_{ij}, t_{ij}, u_{ij})$

Step 5. Calculate crisp relative importance weights (priority vectors) for factors by adopting the center of gravity.

Step 6. The consistency test (Saaty, 1980) is performed by calculating the consistency index (CI) and consistency ratio (CR). If the consistency test is not passed, the expert will be asked to re-do the part of the questionnaire.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (16)$$

$$CR = \frac{CI}{\mathrm{RI}} \quad (17)$$

where $\lambda_{\max}$ is the largest eigenvalue of $\mathbf{A}_1$, n is the number of items being compared in the matrix, and RI is random index defined by Saaty (1980). If CR is less than 0.1, the threshold for consistency, the expert's judgment is consistent. If the consistency test is not passed, the expert will be asked to re-do the part of the questionnaire.

Step 7. Calculate the weights of sub-criteria, the interdependence among sub-criteria with respect to the same upper-level criterion, and the performance of suppliers with respect to each sub-criterion using a similar procedure from Step 3 to Step 6.

Step 8. Form an unweighted supermatrix. The local priority vectors calculated from Step 5 and 7 are entered in the appropriate columns of a matrix, known as an unweighted supermatrix, as follows.

$$\mathbf{S} = \begin{array}{l} \\ \text{Goal} \\ \text{Criteria} \\ \text{Sub-criteria} \\ \text{Alternatives} \end{array} \begin{array}{cccc} \text{Goal} & \text{Criteria} & \text{Sub-criteria} & \text{Alternatives} \\ \end{array} \begin{bmatrix} \mathrm{I} & & & \\ w_{21} & \mathrm{W}_{22} & & \\ & \mathrm{W}_{32} & \mathrm{W}_{33} & \\ & & \mathrm{W}_{43} & \mathrm{I} \end{bmatrix} \quad (18)$$

where w_{21} is a vector that represents the impact of the goal on the criteria, $\mathbf{W}_{32}$ is a matrix that represents the impact of criteria on sub-criteria, $\mathbf{W}_{22}$ indicates the interdependency of the criteria, $\mathbf{W}_{43}$ is a matrix that represents the impact of criteria on each of the alternatives, $\mathbf{W}_{33}$ indicates the interdependency of the sub-criteria, and $\mathbf{I}$ is the identity matrix (Saaty 1996).

Step 9. Transform the unweighted supermatrix into a weighted supermatrix (Saaty, 1996; Lee, Chen and Tong, 2008).

Step 10. Calculate the limit supermatrix. The weighted supermatrix is raised to powers to obtain the limit supermatrix.

Step 11. Rank the suppliers. The priority weights of the suppliers can be found in the alternative-to-goal block, i.e. block (4,1), in the limit supermatrix.

Step 12. Construct a GP model for the green and low-carbon supplier selection and order allocation problem. Set the GP model based on the results from Step 11 to maximize satisfaction:

$$\text{Max } Z_0 = g_1 \times G_1 + g_2 \times G_2 + \ldots + g_n \times G_n \quad (19)$$

Step 13. Formulate the GP model by adopting equations (21) to (27) to minimize the aspiration level of i^{th} objective. It is as follows:

$$\text{Min } Z = \sum_{i=1}^{n} \frac{g_i}{L_i}(d_{i1}^{+} + d_{i1}^{-} + L_i(d_{i2}^{+} + d_{i2}^{-})) \quad (20)$$

$$\text{s.t. } f_i(X) - d_i^{+} + d_i^{-} = \sum_{j=1}^{m} g_{ij} S_{ij}(B) \quad = 1,2,\ldots,n \quad (21)$$

$$f_i(X) - d_{i1}^{+} + d_{i1}^{-} = g_i^{\max} z_i + g_i^{\min}(1 - z_i) \quad i = 1,2,\ldots,n \quad (22)$$

$$\frac{1}{L_i}(g_i^{\max} z_i + g_i^{\min}(1 - z_i)) - d_{i2}^{+} + d_{i2}^{-} = \frac{1}{L_i}(g_i^{\max} \; or \; g_i^{\min}) \quad i = 1,2,\ldots,n \quad (23)$$

$$d_i^{+}, d_i^{-}, d_{i1}^{+}, d_{i1}^{-}, d_{i2}^{+}, d_{i2}^{-} \geq 0 \quad i = 1,2,\ldots,n \quad (24)$$

$X \in B$ (***B*** is a feasible set) (25)

$$z_i \in \{0,1\} \quad (26)$$

4 A CASE STUDY

A case study is used to examine the practicality of the proposed FANP with GP model. A committee of experts in the IC industry is formed to define the problem of supplier selection. A questionnaire is constructed and is targeted on the experts in the IC design company. Based on the collected opinions of the experts and the proposed model, the performance results of the suppliers can be generated. The five criteria and their respective sub-criteria are listed in Table 2.

Table 2: Criteria and sub-criteria of FANP.

Criteria	Sub-criteria
C1 Purchasing management	C_{11} Low pollution
	C_{12} Material label
	C_{13} Recycling
C_2 Process management	C_{21} Modularization
	C_{22} Process control
	C_{23} Technology level
	C_{24} Process improvement capability
C_3 Quality control	C_{31} Environmental regulation fulfilment
	C_{32} Product quality control
	C_{33} Capability of handling abnormal products
	C_{34} Delivery quality and date
	C_{35} Quality certification
C_4 Business management	C_{41} Internal education and training
	C_{42} Green R&D design capability
	C_{43} Pollution control
	C_{44} Regulation of harmful material control
C_5 Cost control	C_{51} Production cost
	C_{52} Business cost
	C_{53} Purchase cost

5 CONCLUSIONS

Green and low carbon supplier evaluation selection and selection is a very complicated process involving interrelationship among two or more firms in a supply chain, and the process is multi-objective in nature. This research thus develops a model for fulfilling the task. Based on the selected criteria and sub-criteria, fuzzy analytic network process (FANP) is used to evaluate various aspects of suppliers, and the most suitable suppliers for cooperation can be obtained. Goal programming (GP) is applied next to allocate the most appropriate amount of orders to each of the selected suppliers. In the future, a case study will be carried out to examine the practicality of the proposed model. The results shall be a reference for selecting and allocating orders to the best green and low carbon suppliers.

ACKNOWLEDGMENTS

This work was supported in part by the National Science Council in Taiwan under Grant NSC 99-2632-H-216-001-MY2-2-4.

REFERENCES

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy Sets and Systems*, 17(3), 233-247.

Chang, C. T. (2007). Multi-choice goal programming. *Omega: The International Journal of Management Science*, 35(4), 389-396.

Charnes, A., Cooper, W. W. (1961). *Management Model and Industrial Application of Linear Programming.* New York: Wiley.

Friedman, T. L., 2008. *Hot, Flat, & Crowded: Why We Need a Green Revolution and How It Can Renew America.* New Kensington: Christian Large.

Kang, H. Y., Lee, A. H. I., Yang, C. Y. (2010). A fuzzy ANP model for supplier selection as applied to IC packaging. *Journal of Intelligent Manufacturing*. on-line.

Lee, A. H. I. (2009). A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert Systems with Applications*, 6, 2879-2893.

Lee, A. H. I., Chen, H. H., Tong, Y., 2008. Developing new products in a network with efficiency and innovation. *International Journal of Production Research*, 48(17), 4687-4707.

Lee, A. H. I., Kang, H. Y., Chang, C. T. (2009). Fuzzy multiple goal programming applied to TFT-LCD supplier selection by downstream manufacturers. *Expert Systems with Applications*, 36, 6318-6325.

Lee, A. H. I., Wang, W. M., Lin, T. Y. (2010). An evaluation framework for technology transfer of new equipment in high technology industry. *Technological Forecasting & Social Change*, 77, 135-150.

Saaty, T. L. (1980). *The Analytic Hierarchy Process.* New York: McGraw-Hill.

Todeva, E., Knoke, D. (2005). Strategic alliances and models of collaboration. *Management Decision*, 43(1), 123-148.

Wang, G., Huang, S. H., Dismukes, J. P. (2004). Product-driven supply chain selection using integrated multi-criteria decision-making methodology. *International Journal of Production Economics*, 91, 1-15.