

Prioritization of Competitive Priority in Cleaner Production Implementation

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Abstract - The aim of this paper is to identify the cleaner production implementation of a manufacturing firm to select the competitive priority in environmental uncertainty. The research methodology employed was fuzzy analytic hierarchy process. It proved to be an efficient tool in handling the fuzziness of the data involved in deciding the preferences of different criteria in order to select the alternatives. Each comparison is converted in the form of triangular fuzzy numbers to construct fuzzy pairwise comparison matrices. The different decision criteria involved in the prioritization of the alternatives in the case firm was discussed in relation to available literature and experts' opinions. The proposed model, from literature, can provide a framework for the organization to prioritize the competitive priority in cleaner production implementation. The research finding shows that the study firm should choose flexibility as major competitive priority under environmental uncertainty.

Keywords - Cleaner production, competitive priority, fuzzy analytic hierarchy process

I. INTRODUCTION

Cleaner production (CP) refers to the product development and the decrease in the waste generation that causes a reduced environmental impact throughout its life cycle [1]. It is the continuous application of an integrated preventative environmental strategy to processes, products, and services so as to increase efficiency and reduce the risks to humans and the environment [2]. Some recent studies advocated that many firms implementing CP programs have gained positive results [3, 4]. There have been several approaches and models that suggested for the CP introduction and implementation. Tseng et al. [5, 6] used a structural equation model to prove that the key internal organizational factors have a positive relationship with CP implementation and a positive impact on operational performance. However, the management is challenged in choosing their competitive priority for environmental uncertainty and intensive competition is inherent in imperative CP implementation. The study of Stone [7, 8] suggested that a set of key

internal organizational factors (leadership, support, communication, involvement and program design) that strongly contributed towards the adoption of CP also affected the potential of ongoing improvement. It further emphasized the importance of social factors in the implementation of CP projects and identified a number of inadequacies in the changing management processes.

One of the starting points to achieving both heightened competitiveness and social responsibility in the market is the alignment of competitive priorities with CP. Cox and Blackstone [9] states that "To be most effective, the manufacturing should act in support of the overall strategic directions of the business and provide for its competitive priorities." As the organization becomes more and more dependent on their competitive priorities, the consequence of poor prioritization has become critical that excessive delays or additional management costs might be incurred if management decisions are not well thought of. Therefore, an effective prioritization process is necessary for the manufacturing firm to build up its major competitive advantage.

Thus, the overall objective of this study is to identify the competitive priority which can stand on the organization's functions. This was accomplished through the use of fuzzy analytical hierarchy process (FAHP) which uses triangular fuzzy numbers to represent the comparison judgments of decision makers [10, 11]. It was employed to decide the final priority among the different alternatives. Knowledge and critical information were taken from CP literature and a group of experts in the industry for the competitive priority selection. A main consideration was the appropriateness of management criteria to its planned level of effort to reach the competitive priorities. The corresponding importance of one criterion over another was decided according to the priorities of the firms. It considers the important decision criteria in cross organization like organizing system and techniques, assessment and feedback, and training and people aligned with deciding the best competitive priority.

The developed approach can adequately handle the inherent uncertainty and imprecision of the human decision making process and provide the flexibility and robustness needed for the decision maker to understand the decision priorities. These merits of the approach would facilitate its use in real-life situations for making effective decisions.

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II. METHODOLOGY

The methodology consists of evaluation of the alternatives in two phases. The first phase focuses on determining the each importance through the formulation of a decision framework from literature review. The second phase encompasses the computations involved in FAHP and description of the development of pairwise comparisons for each of the dependency relationships.

A. The decision framework

CP implementation requires its integration into the whole organization. A continuous and open system based on management leadership to the organization structure, and the communication to customers, as well, is essential for its success [8, 9]. Moors et al. [12] found that some firms regard the environment as a new strategic consideration. Hence, they are taking a proactive stance toward the environment to capture a competitive priority. Dale and Lascelles [13] concluded in their study that it is impossible to identify a unique detailed implementation plan clarifying the order in which particular tools and technology should be used, but specified a variety of starting points and motivations for continuous improvement. Henderson [14] suggested that assessment can make comprehensive, systematic and regular views of an organization's activities, resulting to improvement actions. This process helps organizations identify their strengths, shortcomings and best practices. With a common organizational direction and an increased consistency of purpose, it can provide organizations with opportunities to build greater unity in pursuit of initiatives that effect improvement. In other words, assessments are a means that help analyze an organizations' status quo in implementing the CP and in achieving their strategic objectives.

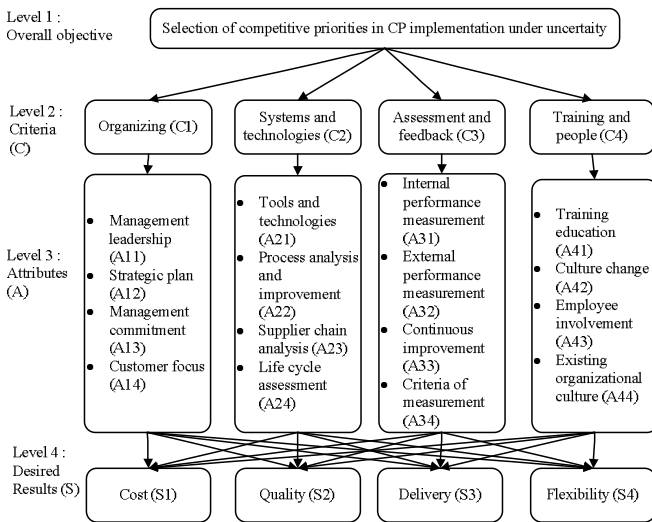


Fig. 1. Hierarchy for the selection of competitive priority in CP implementation.

Assessments are carried out through evaluation of organizational factors, factors that are characteristic to a particular enterprise which influences the level of implementation of preventive environmental options. These include the size and situation of the company, its industrial sector, the available infrastructure (including the type and state of the equipment used and other characteristics of its infrastructural environment) and human behavioral patterns like the motivation and awareness of the employees and organizational culture [15]. An exhaustive list of crucial elements integrated from literature on CP implementation is shown in Fig. 1.

B. Fuzzy AHP

The proposed FAHP uses the triangular fuzzy numbers as a pairwise comparison scale for deriving the priorities of different selection criteria, attributes and alternatives. The fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It has the advantage of mathematically representing uncertainty and vagueness, and adequately providing formalized tools for dealing with the imprecision intrinsic to many problems.

The proposed method uses the triangular fuzzy numbers as a pairwise comparison scale for deriving the priorities of different selection elements, which are based on the importance assigned by experts to each element. Synthesizing experts' opinions complies with the geometric mean method. The valuation scales used in the study are those recommended by Saaty [16], shown in Table I.

TABLE I.
VALUATION SCALE BY SAATY

Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance

Even numbered values will fall in between importance levels. Reciprocal values (e.g. 1/3, 1/5, etc.) mean less importance, strongly less importance, and so on. Only the upper triangle of the matrix needs to be completed. The lower triangle of the pairwise comparison matrix is composed of reciprocal values. Fuzzy numbers were set up in the all hierarchies. Triangular fuzzy membership function is presented in (1).

$$\mu(x) = \begin{cases} 0 & x < a \\ (x-a)/(b-a) & a \leq x \leq b \\ (c-x)/(c-b) & b \leq x \leq c \\ 0 & c \leq x \end{cases} \quad (1)$$

Triangular fuzzy number is adopted, as in (2).

$$[a^\alpha, c^\alpha] = [(b-a)\alpha + a, -(c-b)\alpha + c], \alpha = [0, 1] \quad (2)$$

Synthesize experts' opinions and establish fuzzy matrices. The geometric mean method, shown by (3), was employed to generalize the opinions of experts.

$$a_{pq} = \left(\prod_{k=1}^s a_{pqk} \right)^{1/s}, \forall k = 1, 2, 3, \dots, s. \quad (3)$$

Where $k = 1, 2, \dots, s$ can be expressed as a_{pqk} , the synthetic fuzzy set representing the relative importance level between factor p and q ; s is the number of respondents, and; the relative importance level between factors p and factor q as rated by expert k

Kwong and Bai [17] presented that μ can be incorporated in the calculations to indicate a certain degree of uncertainty for experts to judge $\tilde{A}$, known as index of optimism. That is, μ can be a parameter in an α -cut fixed. Therefore, it follows in (4):

$$A^k = \begin{pmatrix} \overset{a}{(a_{11l}, a_{11u})} & \overset{a}{(a_{12l}, a_{12u})} & \dots & \dots & \dots & \overset{a}{(a_{1nl}, a_{1nu})} \\ \overset{a}{(a_{21l}, a_{21u})} & \overset{a}{(a_{22l}, a_{22u})} & \dots & \dots & \dots & \overset{a}{(a_{2nl}, a_{2nu})} \\ \dots & \overset{a}{(a_{ijl}, a_{iju})} & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \overset{a}{(a_{n1l}, a_{n1u})} & \overset{a}{(a_{n2l}, a_{n2u})} & \dots & \dots & \dots & \overset{a}{(a_{nnl}, a_{nnu})} \end{pmatrix}$$

$$a_{ij}^\alpha = \mu a_{ij}^\alpha + (1-\mu) a_{ij}^\alpha, \quad \forall \mu \in [0, 1] \quad (4)$$

$\alpha = [0, 1]$ and $\mu = [0, 1]$ indexes of optimism was used to obtain a de-fuzzified matrix presented below.

$$\tilde{A} = \begin{pmatrix} \overset{au}{a_{11}} & \dots & \dots & \dots & \overset{au}{a_{1n}} \\ \overset{au}{a_{21}} & \dots & \overset{au}{a_{pq}} & \dots & \overset{au}{a_{2n}} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \overset{au}{a_{n1}} & \dots & \dots & \dots & \overset{au}{a_{nn}} \end{pmatrix}$$

$\tilde{A}$ is a fuzzy matrix with $n \times n$ dimensions. The fuzzy eigenvalues were decomposed, resulting to an eigenvector. The weight vectors with respect to each element under a certain criterion was developed using the principle of the comparison of fuzzy numbers. The priority weights of the CP implementation and each competitive priority were calculated. λ was expressed as a set of fuzzy eigenvalues, whereas $\forall \lambda \in$ real numbers. $\tilde{x}$ is a non-zero fuzzy eigenvector reported as:

$$\tilde{x} = \begin{pmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{pmatrix}$$

λ was decomposed using (5) to obtain $\lambda_{\max} (\lambda_1, \lambda_2, \lambda_3, \dots, \lambda_n)$.

$$\tilde{A}\tilde{x} = \lambda\tilde{x} \quad (5)$$

Saaty [19] proved that for a consistent reciprocal matrix, the $\lambda_{\max}$ value should be equal to the number of comparisons, or $\lambda_{\max} = n$. Then, he also gave a measure of consistency, called consistency index (C.I.) as a deviation or degree of consistency using the following formula (6):

$$C.I. = (\lambda_{\max} - n)/(n - 1) \quad (6)$$

Where n is the number of factors that had been compared

If C.I. is smaller or equal to 10%, the result is acceptable. If it is greater than 10%, the subjective judgment needs to be revised. If $\lambda_{\max} = 0$, complete consistency exists within judgment procedures, whereas if $\lambda_{\max} = n$, the consistency ratio (C.R.) of C.I. to the mean random consistency index (R.I.) whose value should be less than 0.1, is expressed in (7).

$$CR = CI/RI \quad (7)$$

Saaty randomly generated reciprocal matrix using scale 1/9, 1/8, 1/7, ..., 1, ..., 8, 9 to get the random C.I. to see if it is about 10% or less. The priority weights in the same hierarchy were computed through normalization after the eigenvectors were decomposed. The normalized weight vectors are represented by $W = (x_1, x_2, \dots, x_n)$.

III. RESULTS

A group of nine (9) experts consisting of academicians and professionals from printed circuit board (PCB) manufacturing firms were tasked to make pairwise comparison of the different criteria, attributes and alternatives through a questionnaire. Table II presents the pairwise comparison matrix for criteria with respect to the overall objective (Goal). The eigen-vector was computed using MATLAB 6.5. λ was decomposed by (5) to obtain $\lambda_1 = 9.0035$, $\lambda_2 = -2.4295 + 6.1990i$, $\lambda_3 = -2.4295 + 6.1990i$, $\lambda_4 = 0.1518$.

In Table II, $\lambda_{\max}$, equal to 9.0035, was used to further examine the consistency index. It should be less than 0.1 for the result to be acceptable. The calculated C.I. was 0.004 whereas C.R. was 0.006. Therefore, the results are acceptable and consistent. The resulting $\tilde{x}$ (eigenvector) is [0.47, 0.55, 0.53, 0.44]. The normalized priority weights are presented as Local $W_g = [0.24, 0.28, 0.27, 0.22]$.

TABLE II.
PAIRWISE COMPARISON MATRIX FOR CRITERIA IN GOAL

Goal	C1	C2	C3	C4	e-vector($\tilde{x}$)	Local W_g
C1	1	1/8	6 8/9	1/6	0.47	0.24
C2	8	1	1/3	1	0.55	0.28
C3	1/7	2 5/6	1	6	0.53	0.27
C4	6	1	1/6	1	0.44	0.22

$\lambda_{\max}=9.0035$ C.I. = 0.004 C.R. = 0.006

TABLE III.
PAIRWISE COMPARISON MATRIX FOR ATTRIBUTES (ALL~14) IN C1

C1	A11	A12	A13	A14	e-vector($\tilde{x}$)	Local W_{cl}
A11	1	7	1 1/4	1 1/3	0.81	0.48
A12	1/7	1	6 5/7	7 1/3	0.52	0.31
A13	4/5	1/7	1	1 3/7	0.19	0.11
A14	3/4	1/7	5/7	1	0.16	0.10

$\lambda_{\max}=9.121$ C.I. = 0.015 C.R. = 0.011

Table III presents $\lambda_{\max}$, C.I. and C.R. values. The results are acceptable and consistent. $\tilde{x}$ was obtained as [0.81, 0.52, 0.19, 0.16]. Local W_{cl} = [0.48, 0.31, 0.11, 0.10].

The whole process was repeated for all the pairwise comparison matrices. The completed result of alternatives to goal and global weight priority is shown in Table IV. The fuzzy evaluation matrices of decision alternatives and corresponding weight vector of each alternative with respect to corresponding attributes were determined. The fuzzy evaluation matrices of attributes and the weight vectors of each attribute are presented. The weights of competitive priority with respect to the each criterion were computed by adding the weights of each competitive priority multiplied by weights of the corresponding attributes. The weights of each competitive priority can be calculated by multiplying the weights of each competitive priority by the weights of the corresponding criterion. The highest score of the alternative (flexibility) gives the idea about the best competitive priority in CP implementation under environmental uncertainty.

TABLE IV.
GLOBAL LOCAL PRIORITY WEIGHTS OF COMPETITIVE PRIORITY IN CP IMPLEMENTATION

C1		A11	A12	A13	A14	Local W_{c1}
0.48	S 1	0.06	0.23	0.06	0.08	0.11
0.31	S 2	0.07	0.27	0.21	0.18	0.16
0.11	S 3	0.48	0.27	0.66	0.33	0.42
0.10	S 4	0.39	0.23	0.07	0.41	0.31
C2		A21	A22	A23	A24	Local W_{c2}
0.31	S 1	0.05	0.09	0.08	0.20	0.08
0.27	S 2	0.15	0.21	0.36	0.26	0.25
0.33	S 3	0.62	0.30	0.11	0.38	0.34
0.09	S 4	0.18	0.40	0.46	0.17	0.33
C3		A31	A32	A33	A34	Local W_{c3}
0.45	S 1	0.13	0.20	0.04	0.05	0.10
0.11	S 2	0.19	0.17	0.12	0.15	0.16
0.35	S 3	0.25	0.45	0.43	0.47	0.35
0.09	S 4	0.43	0.19	0.41	0.32	0.39
C4		A41	A42	A43	A44	Local W_{c4}
0.21	S 1	0.12	0.06	0.39	0.06	0.12
0.36	S 2	0.18	0.07	0.23	0.22	0.16
0.14	S 3	0.51	0.48	0.15	0.06	0.32
0.30	S 4	0.19	0.39	0.24	0.66	0.41
Goal		W_{c1}	W_{c2}	W_{c3}	W_{c4}	Global W_g
0.24	S 1	0.11	0.08	0.10	0.12	0.10
0.28	S 2	0.16	0.25	0.16	0.16	0.17
0.27	S 3	0.42	0.34	0.35	0.32	0.36
0.22	S 4	0.31	0.33	0.39	0.41	0.37

IV. DISCUSSION

The strategic organizational direction will not only be affected by the organizational decisions, but also by uncertainty. The fuzzy environment in the long ran might be presented with more uncertainty during the decision making process because the management is facing an uncertain future. Therefore, FAHP is proposed as the research methodology to address the problem. The study verified that quality was the most dominant competitive priority for CP implementation in the PCB firm through the analysis of empirical evidences. Flexibility provided the supporting role in the CP implementation process. Moreover, the resulting local weights of objective to criteria have also shown that a majority attributes ranked

higher. Particularly, system and techniques (0.28) and assessment and feedback (0.27) were the most important criteria (Table 2). The findings affirmed the argument that the CP was a kind of technological philosophy rather than a management. This helped organizations identify their strengths to drive towards technologies and tools (0.08), process analysis and improvement (0.25), supply chain analysis (0.34), and life cycle assessment (0.33) under system and techniques (C2 - Ranked 1). In addition, the evaluators' designation of critical weights also provided good insights of their individual focus on the CP implementation.

The FAHP is proved to be simple, being less time-consuming and having less computational expense as compared to other existing decision-making methods. The use of FAHP does not involve cumbersome mathematical operation, thereby, making it of general use for solving practical multi-attribute decision making problems. The FAHP has proven its ability to capture the vagueness of human thinking style by effectively solving the study problem. The illustrative example has demonstrated the flexibility and efficiency of the proposed model to directly tap the subjectivity and preferences of the decision makers. The following can be concluded from this study:

1) In general, to ensure the success of CP implementation, the managers must look into flexibility as a major competitive priority under environmental uncertainty.

2) CP implementation is strategically important when organizing, system and techniques, assessment feedback and training and people were considered in the decision framework from various literature.

3) The results of the study provide good insights into identifying and prioritizing the criteria, attributes and alternatives for the implementation of CP for it aligned the competitive priority and CP implementation in strategic point of view although it only focused on the case PCB manufacturer.

The FAHP approach was able to determine the most crucial competitive priority in CP implementation under uncertainty. The large number of criteria and attributes demonstrated the complexities involved in the prioritization. It has made a significant contribution by identifying and emphasizing the important criterion under uncertainty and paved the way for its application in current business scenario. Given the aforementioned various advantages of the proposed approach for the competitive priorities prioritization, this research work can be extended to add more competitive priority alternatives, including the incorporation of international PCB manufacturers in the selection.

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