MULTI CRITERIA DECISION ANALYSIS AND ITS APPLICATION TO TECHNOLOGY SELECTION*

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ABSTRACT: *Recently, environmental technologies are widely available to prevent pollution from industrial activities. The term Best Available Techniques (BAT) refers to technologies that can be used to overcome certain environmental problems. The selection of the right technology for pollution prevention involves a complicated process. Not only technical and economic aspects, but also environmental aspect should be considered as well. However, environmental aspect is difficult to quantify due to uncertainty in the real value of the environment. The aim of this study is to develop a framework for decision making process that incorporates the three aspects: technical, environmental, and economic in selecting the best technology which is relevant to a certain textile industry. One multi criteria decision analysis tool, Analytic hierarchy process (AHP), is used in this study to help decision maker in a textile industry to compare and rank three alternative technologies: substitution of mineral oil, pre-wetting process and compact spinning technology. Substitution is the most feasible option having benefit/cost (B/C) ratio 2.154, followed by compact spinning with B/C ratio 0.761 while pre-wetting is the last option with B/C ratio 0.879. The result shows that AHP is capable to quantify both qualitative and quantitative criteria to aid decision maker in comparing several options and determining the best option.*

Keywords: *AHP, BAT, decision making, textile industry.*

1. INTRODUCTION

The conflict between economy and environment has long been recognized. Solutions to environmental problems are perceived as a burden to economic wealth of an organization and the sustainability of the industry. Therefore, organizations, particularly industries, are very reluctant to implement pollution control technologies. Recently, there is a growing interest in using a win-win approach in which the technique used also gives economic benefits for industry. Best Available Techniques (BAT) are the techniques used by industrial enterprises that have the lowest impact on the environment without compromising the economic health of the industry (Dijkmans, 2000). Several organizations such as US EPA, European Union IPPC, UNEP, and Environment Australia, release books that contain information for BAT in a particular industrial sector to help decision makers in industries to determine and adopt certain technique to reduce their environmental impacts (US EPA, 1997, IPPC, 1996, World Bank, 1998). However, the decision regarding the best option in environmental technologies consists of a set of complex interrelated aspects and multiple attributes.

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In the case of environmental area, it is very difficult to determine decision that involves qualitative factors such as the degree of pollution, the environmental degradation, and the social impact of the technique implemented to company image. When faced by options, very often decision makers selected the best option based on their intuition, judgment, knowledge and experience, thus the decision may not be the best decision because of several reasons:

- Individual knowledge and experience are inadequate in making decision that involves various interrelated factors (Saaty, 1980).
- There is a tendency to reduce the criteria and decide based only on one important criterion, or several criteria in the order of their importance or known as lexicographic and semi-lexicographic strategies (Goodwin and Wright, 1998).
- The possibility to eliminate good alternatives because it failed to meet one criterion even though it may be superior in other criteria.

The selection of the environmental technology or best available technology in particular industry can be categorized as a complex problem. Not only technical criterion should be considered, but also economic, social, and environmental issues should be taken into account. Among these criteria, some are easily quantified such as investment cost, operational and maintenance cost, savings from raw material, energy, water and waste treatment, and productivity. However, some factors are categorized as qualitative such as emission reduction, environmental quality improvement, liability, and social impacts related to company image and customer preference. Thus, these factors are often ignored in decision-making process.

Because of the above reasons, there is a necessity to develop a normative decision-making framework in which one can use to rank the alternatives and choose the best choice by integrating the quantitative and qualitative factors. There are several multi-criteria decision techniques that have been developed as decision-making tools including goals programming, scoring model, MAUT/Multi-Attribute Utility Theory, SMART/Simple Multi Attributes Rating Technique, SMARTER/modification of SMART, PROMETHEE/Preference Ranking Organization Method for Enrichment Evaluations, and AHP/Analytic Hierarchy Process (Keeney, 1994, Dyer et al., 1995, Castro and Jimenez, 2005, Saaty, 1980). Among those tools, AHP has gained wide popularity due to its simplicity and flexible structure (Forman and Gass, 2001). In environmental area, AHP is used as decision-making tool in energy selection, strategic and tactical planning for managing national park resources, criteria and indicators prioritization for sustainable forest management, resource allocation, and corporate social responsibility (Saaty, 1980, Zahedi, 1986, Brice and Wegener, 1989, Schmoldt, 2001).

The analytic hierarchy process (AHP) is a decision analysis technique used to evaluate complex multi-attributed alternatives with conflicting objectives among one or more actors (Saaty, 1980). AHP was developed by Saaty to assist decision makers to decide or prioritize and arrive at the best decision.

The aim of this research is to develop a framework for decision making process to be used in determining the best available technique in textile industries. The framework is then applied in a textile company to choose one technique among the three alternatives of pollution prevention strategies.

2. METHODOLOGY

The methodology used in this research can be divided into two parts. The first part develops a framework for decision-making process which involves the hierarchy development and the second part deals with pairwise comparison to determine the relative weight of each criterion in the hierarchy and each alternative.

2.1. Hierarchy Development

Hierarchy development involves breaking down the problem into its smaller constituent parts. AHP is a systematic procedure that decomposes a complex problem into a hierarchy (Saaty, 1980). The hierarchy consists of several levels in which the first level shows the overall goal, the second level mentions the criteria used to evaluate the alternatives with regards to the overall goal, and the third level is the elaboration of the second level of the hierarchy. The last level is the alternatives which the decision makers have to choose. In this study, the hierarchies were determined from the survey distributed to several textile companies containing some criteria used by those companies to make decision in selecting new technologies or processes.

2.2. AHP Application in Textile Company X

The company used as a case study in this research is intended to implement environmental management system in its operations. During the initial assessment, there were three alternatives of pollution prevention strategy that can be implemented to reduce COD level caused by its activity. These three alternatives are: subsitution of mineral oil with hydrosoluble oil, addition of new process called pre-wetting the warp yarn, and replacement of ring spinning technology with compact spinning.

The application of AHP to choose the best option involves the following steps:

a. Elicit judgment using pairwise comparisons and represent those judgments with meaningful number.
   A pairwise comparison is the process of comparing the relative importance, preference, or likelihood of two elements in the hierarchy. These judgments express the relative strength of the elements using 1-9 scale as shown in table 1. The result of pairwise comparisons is represented in a square matrix in which each judgment represents the dominance of an element in the columns on the left over an element in the row on top.
b. Use the numbers to calculate the priorities of the elements of the hierarchy
   Once the matrix have been filled with 1-9 scale, the relative weight of each element then can be calculated using the process called synthesization.
c. Synthesize these results to determine the overall outcomes for benefit (B) and cost (C) using the formula:

$$B = \sum_{j=1}^{N} a_{ij}.w_j \qquad C = \sum_{j=1}^{M} a_{ij}.w_j$$

where i = the number of alternative

j = the number of criteria or sub-criteria

N = the number of sub-criteria in the benefit hierarchy

M = the number of criteria in the cost hierarchy

a_{ij} = priority for each alternative

w_j = priority for each criterion or sub-criterion

Table 1. Comparison Scale for the Importance of Criteria Using AHP (Saaty, 1994a)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it
Reciprocals	If activity i has one of the above non zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A comparison mandated by choosing the smaller elements as the unit to estimate the larger one as a multiple of that unit.

d. Check the consistency ratio
   Inconsistency may happen in the following situation: one compares B to A as 2 to 1 and C to B as 3 to 1, and C is 8 times more important than A. According to Saaty (1994b), inconsistency may be thought as an adjustment needed to improve the consistency of the comparisons, but the adjustment should not be as large as the judgment itself. One indicator to measure the consistency is the consistency ratio (CR). Higher number of CR means that the decision maker is less consistent with his answers.
e. Analyze the sensitivity to changes in judgment
   Sensitivity analysis shows the sensitivity of the alternatives with respect to all the criteria under the overall goal. In some cases, the decision maker may not be very confident with the weight assigned for each criterion and wants to know what happens when he changes the priorities. Sensitivity analysis provides answers on how the changes in criteria's priorities affect and alter the rank of the alternatives.

3. RESULTS AND DISCUSSION

Results of the questionnaires show that decision makers in textile industries considered 3 major aspects when making decision regarding investment in new machines or processes. These three aspects are economy, social, and environmental. The criteria were divided into several sub-criteria as can be seen in Figure 1.

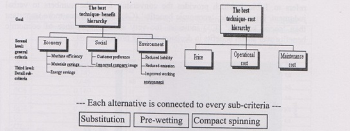

Figure 1. The Two Hierarchies Used in This Study

The judgment elicitation of the respondents were also obtained from the questionnaires in which the decision makers were asked to value their preference of each criterion using pairwise comparisons with respect to the overall goal. The result of judgment elicitation is showed in Table 2 and 3.

Table 2. The Comparison for the Second Level of the Benefit and Cost Hierarchies Based on Textile Companies' Perspective

	C1	C2	C3	C4	C5	C6	w_j
C1	1	3	3	-	-	-	0.6
C2	1/3	1	1	-	-	-	0.2
C3	1/3	1	1	-	-	-	0.2
C4	-	-	-	1	7	3	0.669
C5	-	-	-	1/7	1	1/3	0.088
C6	-	-	-	1/3	3	1	0.243

Note: C1=capital cost, C2=operational cost, C3=maintenance cost, C4=economic benefits, C5=social benefits, C6=environmental benefits, w_j = priority for each criterion

Table 3. The Pairwise Comparisons for the Third Level of the Benefit Hierarchy

	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	P1	w_j
SC1	1	3	3	-	-	-	-	-	0.6	0.402
SC2	1/3	1	1	-	-	-	-	-	0.2	0.134
SC3	1/3	1	1	-	-	-	-	-	0.2	0.134
SC4	-	-	-	1	1	-	-	-	0.5	0.044
SC5	-	-	-	1	1	-	-	-	0.5	0.044
SC6	-	-	-	-	-	1	1	1	0.33	0.081
SC7	-	-	-	-	-	1	1	1	0.33	0.081
SC8	-	-	-	-	-	1	1	1	0.33	0.081
Total										1.00

Note: SC1=machine efficiency, SC2=material savings, SC3=energy saving, SC4=customer preference, SC5=improved company image, SC6=reduced liability, SC7=reduced emission/waste, SC8=improved working environment, P1=priority of the sub-criterion with respect to the higher level of the hierarchy (local), w_j =priority of the sub-criterion with respect to the overall goal (global).

The numbers in the table represent how much more important the element in the left column to the element in the top row. The interpretation of the scores refers to Table 1 which provides the conversion from the numbers to verbal judgment. For example, 'economic benefits' (C4) is seven times more important than 'social benefits' (C5) indicates the very strong importance of economic benefits over social benefits in decision-making process.

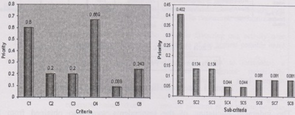

Figure 2. The Priorities/Relative Weights Given for Each Criterion in the Second and Third Level of the Hierarchies

In general, the decision makers in textile companies considered that the capital cost of installing a new machine or process was moderately more important than the operational and maintenance costs. In this assessment, the operational and maintenance costs were deemed to be equally important. The economic benefit arises from the investment in a new machine or process was considered as very important when compared to the social benefit, but only moderately important compared to environmental benefit. This comparison also showed that the environmental factor plays a more important role in the decision-making process than social factor.

In the third level of the hierarchies, machine efficiency is the most important sub-criterion due to quality reason and the cost imposed by the failure to recognize the risk associated with machine efficiency. The next sub-criteria that play an important role in the decision-making process are material and energy savings followed by environmental benefits, which consist of reduced liability, improved working environment, and reduced emissions/waste.

The priorities for each alternative were also obtained from pairwise comparisons which compare the relative importance of the three alternatives to every element in the second level of the hierarchies as can be seen in Table 4 and Figure 3.

As can be observed from Figure 3, the first alternative is superior in two sub-criteria: energy saving, and improved company image, while it has the lowest priority in machine efficiency, customer preference, reduced liability sub-criteria, and cost criteria. The second alternative in general has an average priority for almost all sub-criteria, except for operational and maintenance costs in which it has the highest priority because it requires an additional process and resource. The overall rank for the three alternatives can be determined using benefit and cost ratio.

Table 4. The Priority for Alternatives for Each Criterion and Sub-Criterion

	Substitution of mineral oil (a_{1j})	Pre-wetting the warp yarn (a_{2j})	Compact spinning (a_{3j})
SC1	0.077	0.231	0.692
SC2	0.333	0.333	0.333
SC3	0.690	0.161	0.149
SC4	0.143	0.429	0.429
SC5	0.648	0.122	0.230
SC6	0.169	0.387	0.443
SC7	0.333	0.333	0.333
SC8	0.333	0.333	0.333
C1	0.077	0.231	0.692
C2	0.122	0.648	0.230
C3	0.250	0.500	0.250

Note: SC1=machine efficiency, SC2=material savings, SC3=energy saving, SC4=customer preference, SC5=improved company image, SC6=reduced liability, SC7=reduced emission/waste, SC8=improved working environment, C1=capital cost, C2=operational cost, C3=maintenance cost

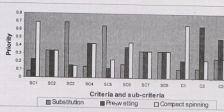

Figure 3. The Summary of Priority Given for Each Alternative

Table 5. The Summary of Benefit and Cost Ratio

	SC1 0.6	SC2 0.2	SC3 0.2	Economy rank	SC4 0.5	SC5 0.5	Social rank	SC6 0.33	SC7 0.33	SC8 0.33	Env rank
S	0.077	0.333	0.690	0.2508	0.143	0.648	0.3955	0.169	0.333	0.333	0.2755
P	0.231	0.333	0.161	0.2374	0.429	0.122	0.2755	0.387	0.333	0.333	0.3475
C	0.692	0.333	0.149	0.5116	0.429	0.230	0.3195	0.443	0.333	0.333	0.3660
	C4 0.669	C5 0.088	C6 0.243	Benefit rank	C1 0.600	C2 0.200	C3 0.200	Cost rank	B/C ratio	Overall Rank	
S	0.2508	0.3955	0.2755	0.280	0.077	0.122	0.250	0.130	2.154	#1	
P	0.2374	0.2755	0.3475	0.290	0.231	0.648	0.500	0.381	0.761	#3	
C	0.5116	0.3195	0.3660	0.430	0.692	0.230	0.250	0.489	0.879	#2	

Based on the comparison of the benefit and cost, the first alternative has the highest benefit/cost ratio and should be implemented in the first place if the company wants to improve its environmental performance by reducing the COD level in the effluent. The subset of the best alternative is the compact spinning technology.

3.1. Consistency Checking

In this study, the consistency ratio ranges from 0.00 to 0.02, which means that the decision maker was relatively consistent with his responses, so there is no need to re-evaluate the pairwise comparisons.

3.2. Sensitivity Analysis

Varying the economic priority, and automatically altering the social and environmental priorities, may reverse the priority between alternatives. The current dynamic sensitivity of the selection of BAT in a textile industry is presented in Table 6.

Table 6. Benefit and Cost Ratio at Various Scenario of Economy, Social, and Environmental Priorities

Priorities			Sub		Pre		C S		Rank
Economy	Social	Environment	B	B/C	B	B/C	B	B/C	Sub, Pre, CS
85.1	4.0	11.0	0.272	2.092	0.270	0.708	0.458	0.936	#1, #3, #2
79	5.6	15.4	0.275	2.115	0.277	0.727	0.449	0.918	#1, #3, #2
66.9	8.8	24.3	0.280	2.159	0.290	0.761	0.430	0.879	#1, #3, #2
48.5	13.7	37.8	0.288	2.215	0.310	0.814	0.403	0.824	#1, #3, #2
46.6	14.2	39.2	0.289	2.223	0.312	0.818	0.400	0.817	#1, #2, #3
45.5	14.5	40.0	0.289	2.223	0.313	0.821	0.398	0.813	#1, #2, #3
12.3	23.3	64.4	0.303	2.331	0.349	0.916	0.348	0.711	#1, #2, #3
Priorities			Sub		Pre		C S		Rank
Economy	Social	Environment	B	B/C	B	B/C	B	B/C	Sub, Pre, CS
71.0	3.3	25.7	0.276	2.123	0.289	0.758	0.435	0.889	#1, #3, #2
69.3	5.5	25.2	0.278	2.138	0.289	0.758	0.433	0.885	#1, #3, #2
66.9	8.8	24.3	0.280	2.159	0.290	0.761	0.430	0.879	#1, #3, #2
29.0	60.5	10.5	0.316	2.431	0.299	0.784	0.384	0.785	#1, #3, #2
28.4	61.3	10.3	0.317	2.438	0.299	0.784	0.383	0.783	#1, #2, #3
27.0	63.2	9.8	0.318	2.446	0.300	0.787	0.382	0.781	#1, #2, #3
Priorities			Sub		Pre		C S		Rank
Economy	Social	Environment	B	B/C	B	B/C	B	B/C	Sub, Pre, CS
82.5	10.8	6.7	0.278	2.138	0.276	0.724	0.446	0.912	#1, #3, #2
78.5	10.3	11.2	0.278	2.138	0.280	0.735	0.442	0.904	#1, #3, #2
66.9	8.8	24.3	0.280	2.159	0.290	0.761	0.430	0.879	#1, #3, #2
50.2	6.6	43.2	0.282	2.169	0.304	0.780	0.414	0.847	#1, #3, #2
39.5	5.2	55.3	0.283	2.177	0.314	0.824	0.403	0.824	#1, #2, #3
37.9	5.0	57.2	0.284	2.185	0.315	0.827	0.401	0.820	#1, #2, #3

Note: B=the overall score/priority for the benefit hierarchy, B/C=benefit per cost ratio, Sub=substitution of mineral oil, Pre=pre-wetting technology, CS=compact spinning technology.

Looking at the overall benefit and cost ratio, which determines the rank of the alternatives, and assuming that the cost hierarchy is constant, a change in the economic priority to 46.6% which in turn increase the priority of social and environmental criteria to 14.2% and 39.2%, will result in the rank reversal for the second and the third alternative. This means that if the decision maker changes the weight assigned for economic sub-criteria to less than 46.6% then the subset of the best alternative will be the pre-wetting technology, while the compact spinning is in the third position.

Using the same method, the order of the alternatives will not change if the social priority increases up to 60.5% and the environmental priority increases to more than 55.3%. The first alternative, the substitution of mineral oil, is superior in almost all conditions, no matter how much the economic, social and environmental criteria are varied. Therefore, it can be concluded that the substitution of mineral oil is the best alternative to be implemented although there are some changes in the weight assigned for each criterion.

4. CONCLUSION

The selection of the best option with regard to the specific industrial condition requires a decision-making tool that enables decision makers to cope with their limitation in facing a complex problem. The application of AHP in decision making process offers several advantages such as leading to the better result, integration of the qualitative and quantitative criteria (such as environmental and social aspects which are difficult to quantity), and its transparency. In addition, AHP provides an audit trail that allows the decision maker to produce a defensible rationale for choosing a particular course of action. The application of AHP in this study to rank and prioritize three environmental technologies for the textile industry shows that substitution of mineral oil is the most feasible option with benefit/cost ratio 2.154; thus this option should be implemented in the first place. The second is compact spinning technology to replace ring spinning machines which has B/C ratio 0.879, followed by the pre-wetting technique which has B/C ratio 0.761. The sensitivity analysis performed in this study showed that change in the preference of economic, environmental, and social factors will not change the order/rank of options if the decision maker does not change the preference less than 46.6%, more than 60.5% and 55.3% for economic, social and environmental criteria, respectively.

REFERENCE

Brice, H., and Wegner, T. A *Quantitative Approach to Corporate Social Responsibility Programme Formulation*. Managerial and Decision Economics Vol 10, No 2, (1989): pp 163-171.

Castro, F., and. Jimenez, M. PROMETHEE: *an extension through fuzzy mathematical programming*. Journal of the Operational Research Society Vol 56 (2005): pp 119-122.

Dijkmans, R. *Methodology for Selection of Best Available Techniques (BAT) at the Sector Level*. Journal of Cleaner Production Vol 8 (2000): pp 11-21.

Dyer, J. S. et al. *Multiple Criteria Decision Making, Multiattribute Utility Theory*: The Next Ten Year. Management Science Vol 38 No 5 (1992): pp 645-654.

Forman, E. H. and Gass, S. I. *The Analytic Hierarchy Process* – An Exposition. Operations Research Vol 49, No 4, (2001): pp 469-486.

Goodwin, P. and Wright, G. *Decision Analysis for Management Judgment*. John Wiley and Sons, Chichester, 1998.

Keeney, Ralph L. Using Values in Operations Research. *Operations Research* Vol 42, No 5, (1994): pp 798-813.

Integrated Pollution Prevention and Control. BAT Reference Notes (BREFs). 1996. http://eippcb.jrc.es/pages/FActivities.htm

Saaty, T. L. *The Analytic Hierarchy Process*. McGraw Hill, New York, 1980.

Saaty, T. L. *Fundamental of Decision Making and Priority Theory with the Analytic Hierarchy Process* Vol VI. RWS Publication, Pittsburgh, 1994a.

Saaty, T.L. How to Make a Decision: *The Analytic Hierarchy Process*. Interfaces Vol 24, No 6, (1994b): pp 19-43.

Schmoldt, D. L., Kangas, J., and Guillermo A. Mendoza. *Basic Principles of Decision Making in Natural Resources and the Environment*. In The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making. Kluwer Academic Publishers, London, 2001: pp. 1-13.

US Environmental Protection Agency. *Best Management Practices for Pollution Prevention in the Textile Industry*: Manual. Center for Environmental Research Information, Cincinnati, 1997.

World Bank. *Pollution Prevention and Abatement Handbook*. 1998. http://www.worldbank.org/nipr/ othresources.htm

Zahedi, F. *The Analytic Hierarchy Process* – a Survey of the Method and Its Application. Interfaces Vol 16, No 4, (1996): pp 96-108.