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An ANP Approach to Multi-Criterial Decision-Making: Selection of Cleaner Production Alternatives for Construction Enterprises

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Abstract: ANP is the most comprehensive framework for the analysis of societal,national and enterprise decision for the decision-maker today, allowing for all possible and potential dependencies. This study uses ANP model to select cleaner production alternatives on basis of enterprises' capacity with internal and external dependences. Cleaner Production (CP) has been considered to be an important means for effective pollution control and lead to a win-win situation of improving economic and environmental benefits. It is operated widely by construction enterprises as a method to cut on environment negative impact. However, to select appropriate CP options have been a key issue for different enterprises to implement cleaner production successfully. CP options could be divided into three types: low-cost, mediate-cost, high-cost. Entensive research has studied on evaluation of CP option but most just considered economic and environmental performances of options. In fact,it is important to concider some CP option on basis of enterprises' background such as CP capacity. This study focused on the relation between the CP capacity of enterprises and CP option, making two contributions: first,we established the evaluation index system of CP capacity in construction enterprises. There is dependence and feedback among elements, so ANP model was used to evaluate. Second, on basis of the complexity of computation process, SuperDesicion software was introduced to calculate the dates and gained the prioritization of the alternatives.

Key words: Leaner production, construction enterprises, CP capacity, ANP

INTRODUCTION

Environmental protection is currently becoming one of the key projects performances in construction industry. Cleaner Production (CP) has been considered to be one of the main activities of the enterprises committed to effective environmental management and lead to a win-win situation of improving economic and environmental benefits. As an effective way to sustainable development strategy in manufacture industries, Cleaner production is a new, creative thinking (UNEP). The implementation of cleaner production in China is still in the initial stage, where mainly showing some mandatory actions (Wang, 2002) and lacking of full initiative and planning in the process (He and Ortolano, 2006). The researches on CP option has been finished by various experts, to generate and select best CP option is very important for enterprises to implement cleaner production. Li (2010) investigated the cleaner production alternatives for saponin industry with material flow analysis (MFA). Xiong *et al.* (2010) presents the application of gray correlation analysis to select the schemes for cleaner production. Basak *et al.* (2010) introduced two indicators of the Internal Rate of Return (IRR) values and payback period to select the best CP options in printed circuit board plant. Zeng *et al.* (2010) analyzed the relationship between cleaner production and business performance using Structure Equation Model (SEM). Extensive researches on selection of CP alternatives has carried out by Quantitative evaluation and just considered the performance of various alternatives. However, different enterprises will choose best CP options by considering their real conditions. Generallly, No-cost and Low-cost and infeasible option can be choose to implement immediately.mid/high-cost ones can be further filtered and studied. Enterprises leaders will select best CP option with feasible investments, which considering the performance of CP option and their CP capacity. In the study, the factors of enterprises' CP capacity will be analyzed.Then the study will evaluate the three kinds of CP alternatives (low-cost, mid-cost, hig-cost) on the basis of these index of CP

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capacity and analyze the results for decision-making support on CP alternatives selection in a case study. According the problem exist complex interaction between decision-making and issues, The Analytic Network Process (ANP) will used in the study.

MCDM AND SUPERDECISION (SD) SOFTWARE

Now decision-making is wildly existed in social, governmental and corporate activities, the Multi-Criteria Decision Making (MCDM) has been one of the fastest growing approach, meaning to evaluate a set of alternatives in term of various criteria. Multi-Criteria Decision Making can deal with quantitative and qualitative criteria, with share the common characteristics of conflict and incommensurable units among criteria. A number of method used in MCDM, including: (1) Elementary method, (2) The single synthesizing criterion approach, (3) The outranking synthesizing approach and (4) The mixed methods. In a word, MCDM approach are divided into two categories: Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM), distinguished on basis of the determination of alternatives. In the study, the problem of CP option based on CP capacity is a problem of MADM, with the aim of selecting the best alternation by comparing between alternative with respect to each attribute. There is extensive research on MADM: Peng weibing discussed MADM method under the uncertain condition of the decision-makers dilemma of the possible regret degree of decision-makers. Gong Bengang proposed D-S theory for MADM with incomplete linguistic assessment information. Zhenhua Zhang introduced some weighted scoring functions based on Intuitionistic Fuzzy Stets with Parameters (IFSP) into MADM to solve dynamic decision making problem and proposed. Weimin Ma resented the intuitionistic fuzzy numbers (IFNs) used in MADM when Decision makers tend to express their preferences in intuitionistic fuzzy form G.W. Wei applied grey relational analysis technique to MADM with incomplete weight information under the condition of intuitionistic fuzzy.

The Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) are both the techniques for Multi-Criteria Decision-Making (MCDM), setting priority of decision. However, the relationship and interaction among selection criteria and their sub-criteria is usually ignored in AHP, but the ANP is able to measure them. With the complexity of decision making in the real world, Computer-aided decision-making technique has been urgently needed to improve the quality and accuracy of decision making. Super Decision (SD) is decision making software based on the analytic hierarchy process and the analytic network process. In the super decision software priorities are derived through a series of pairwise comparisions on the fators of the problem that can including both tangible and intangilble. The quality of decision is very important for a decision-maker, ANP is a reliable and objective approach for making decision and super decision can solve the complexity of computation work.

THE INDEX SYSTEM OF CP CAPACITY FOR CONSTRUCTION ENTERPRISE

Process capacity: Process capacity is the essential element of CP implementation that has been studied by many researchers. Fresner *et al*. (2010) presented the key contents for production process in CP. Cleaner production generally aims at the optimization of material and energy flows by pocess modification, such as technological change and improvement on operation practise. In this study, it includes operation practice, technic innovation, process prevention, management system and safety and emergy schedules.

Collaboration capacity: Collaboration has been considered as an important strategy for successful CP (Zwetsloot and Geyer, 1996; Chiu *et al*., 1999; Gudolf, 2005), especially for supply chain organization. Collaboration is an effective means to take advantage of all the capabilities, resources, risk-sharing, having the strategic importance for construction enterprises to finish CP, because of the insufficiency of economy, technology, awareness and so on. Basing on the characteristics of construction industy, the study introduce consistency of project plan, project information share, stakeholders collaboration, environment strategy alliances, coordination with outside institutes and market adaption as the contents of collation capacity.

Human organizational capacity: It is demonstrated that CP to be unrealistic without the support of human resources, so companies should put more attention into the non-technical factors (human resource practices and factors). Angelo and Charbel (2010) presented the role of human factors in CP implementation for companies and proposed some suggests for improving the adoption of CP based on human factors, including organizational structure, training and others. Extensive literatures has studied on the strong association between human factors and success of CP implementation (Stone, 2006), which suggested that organizational learning, collective commitment and more adoption and implementation of

Table 1: The index system of cleaner production capacity

Cluster	Criteria	Internal dependence	External dependence
Process capacity C1	Operation practice C11	C12, C13	
	Technic innovation C12	C11	C32, C35
	Process prevention C13	C11, C14, C15	C22
	Management system C14	C13, C15	C21
	Safty and energy schedules C15	C13, C14	
Collaboration capacity C2	Consistency of project plan C21	C22	C14
	Project information share C22	C21, C23	C13
	Stakeholders collaboration C23	C22	
	Environment strategy alliances C25	C26	
	Coordination with outside institutes C25		C35
	Market adaption C26	C24	
Human organation capacity C3	Hnman quality C31	C33, C35	
	Hnman management C32		C12
	Organization culture establishment C33	C31, C34	
	Organization operation management C34	C33	
	Continuous improvement C35	C31	C12, C25

advaenced technologies can improve organizational environmental performance (Zwetsloot and Gayer, 1996). Therefore, the integration of human factors or organizational practices into the environmental management strategy of company is a critical challenge (Govindarajulu and Daily, 2004). There are five key issues need to involve: human quality, human management, organization culture establishment, organization operation management, continuous improvement.

Establishing the index System of cleaner production capacity with internal and external dependence, shown in Table 1.

Ne THE DECISION-MAKING MODEL

There are three kinds of CP alternatives for company to implement: low-cost, mid-cost and high-cost. To choose best CP alternatives depending on their capacity is very important for decision-making, so this study established the decision-making model of CP alternatives using the Analytic Network Process (ANP) according to the enterprises' capability.

ANP approach: The Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) are both the techniques for multi-criteria decision-making (MCDM), aiming to identify the priority of a set of criteria for a decision. However, the relationship and interaction among selection criteria and their sub-criteria is usually ignored in AHP but the ANP is able to measure them. ANP can provide a more precision result through solving the problem with dependence and feedback among alternatives or criteria. In a word, the ANP is a generalization of AHP, because it can deal with the problems that allow interactions and feedback within clusters (inner dependence) and between clusters (outer dependence). The study will use the ANP to analyze the relations between CP alternatives and enterprises' capacity in construction, which containing feedback and self-loops among the clusters of decision-making.

Structure of model: The decision-making including four clusters: CP alternatives, process capacity, collaboration capacity and human organization capacity. In order to outline the structure of ANP model,we should determine the dependencies in the network as described in Table 1. There contain feedback and self-loops among the clusters and elements in the model. Straight arrows indicate internal or external dependence of two elements; Loops indicate inner dependence among the elements in the cluster. There are 4 general steps in ANP model, including model construction; paired comparisons between each two clusters or nodes; supermatrix calculation based on results from paired comparisons; and result analysis. In the study, we will use the Super Decisions (SD) software to finish these four steps. The decision-making model has been given in Fig. 1 using SD software. The goal of the model is to gain the priority of key indicator.

Collection of indicator data: Typically, indicators are divided into two types: qualitative and quantitative indicators. The quantitative indicators can be classed in efficiency and cost indicators, the bigger the better for efficiency indicators, whereas the smaller the better for cost index. According the survey data, find the dimensionless number of the indicator by the value of data means setting region-wide indicators, providing an upper limit and under limit in order to convenience the normalized the indicator data. The approach to dimensionless the data is shown in Table 2.

Y_j means the actual value of the jth indicators and y_j^{max}, y_j^{min} are the upper limit and lower limit predetemined of jth, respectively. For qualitative indicators, transfer them to quantitative by scoring the indicators in

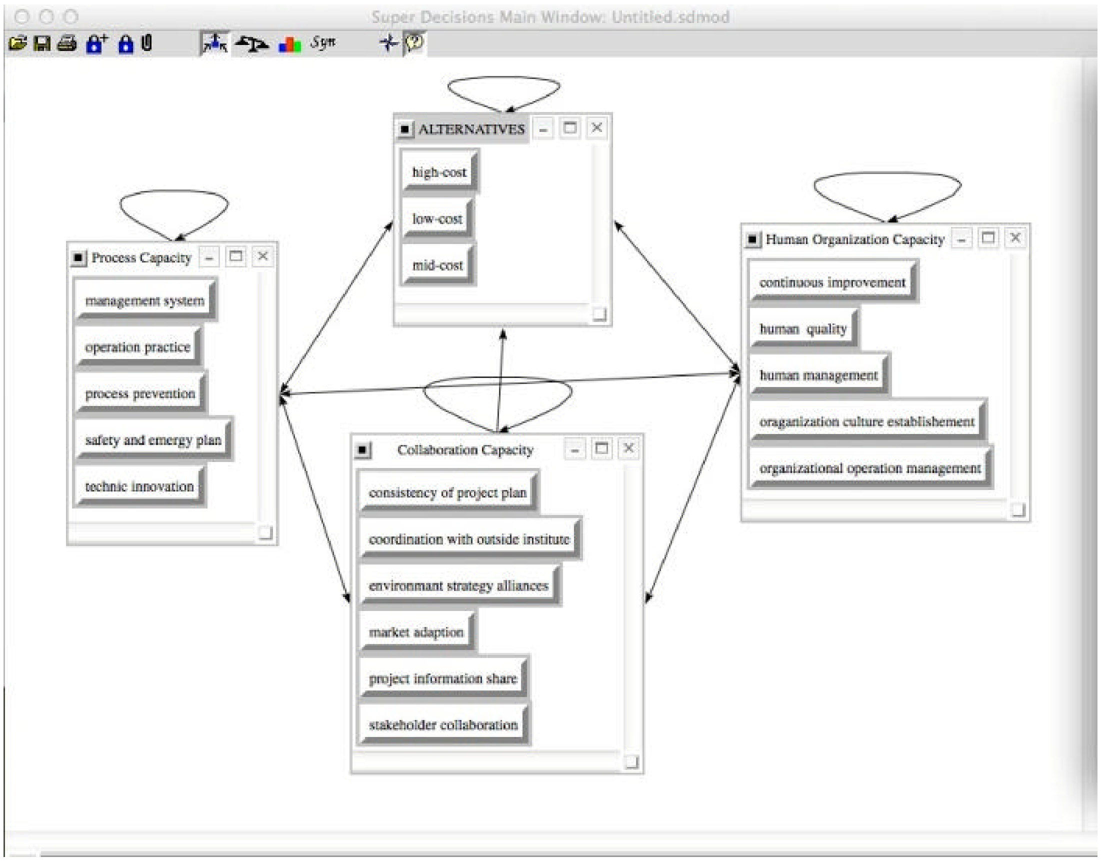

Fig. 1: The decision-making model using ANP

Table 2: Dimensionless process of indicator

Efficiency indicator	Cost indicator
$r_j = \begin{cases} 1, y_j > y_j^{max} \\ \dfrac{y_j - y_j^{min}}{y_j^{max} - y_j^{min}}, y_j^{max} \geq y_j \geq y_j^{min} \\ 0, y_j < y_j^{min} \end{cases}$	$r_j = \begin{cases} 0, y_j > y_j^{max} \\ \dfrac{y_j^{max} - y_j}{y_j^{max} - y_j^{min}}, y_j^{max} \geq y_j \geq y_j^{min} \\ 1, y_j < y_j^{min} \end{cases}$

accordance with wonderful, good, better, average, lower, bad, terrible through interviews experts with their own experience, then dimensionless.

Comparisons and calculation: Numerical judgments are made in a matrix using a nine-point scale that represents how many times one element is more important than another. It is very important that all the comparison questions are asked from the perspective of what is more important or preferred with respect to CP alternatives in the comparisons. In the study, the model is group decision-making problems for company chooses of CP. Facing the kind of problem we need to find an effective way to increase the correctness in decision-making. The paper considers using the geometric mean to process the date collected from the groups of decision makers, which is the most common than other approaches. Its expression is given in the Eq. 1.

$$A_{ij} = [a^1_{ij} \times a^2_{ij} \times \ldots \times a^n_{ij}]^{1/n} \quad (1)$$

In the equation, a^k_{ij} denote the comparison of element i to element j for decision maker k(k = 1, 2,..., n) in pairwise omparison matrix. The individual judgments of the n decision makers are combined using the geometric mean to produce the final result.

ANP method fully takes the feedback and independence between various elements in different clusters, so this computation to evaluation index system is complicated, including: Through comparing various elements with respect to their importance towards the criteria, Matrix W_{ij} is obtained showing the influence of each element of the ith hierarchy on the jth hierarchy:

$$W_{ij} = \begin{bmatrix} w_{i1}^{(j1)} & w_{i1}^{(j2)} & \cdots & w_{i1}^{(jn_j)} \\ w_{i2}^{(j1)} & w_{i2}^{(j2)} & \cdots & w_{i2}^{(jn_j)} \\ \cdots & \cdots & & \cdots \\ w_{in_i}^{(j1)} & w_{in_i}^{(j2)} & \cdots & w_{in_i}^{(jn_j)} \end{bmatrix}$$

Table 3: Limiting priorities and normalized by cluster priorities

Cluster	Criteria	Priorities from limiting matrix	Priorities normalized by cluster
Alternatives	High-cost	0.061340	0.452366
	Mid-cost	0.022576	0.166492
	Low-cost	0.051682	0.381142
Process capacity	Operation practice	0.033086	0.154125
	Technic innovation	0.066378	0.309209
	Process prevention	0.033623	0.156626
	Management system	0.043765	0.203872
	Safe and energy schedules	0.037818	0.176168
Collaboration capacity	Consistency of project plan	0.070107	0.169687
	Project information share	0.066987	0.162135
	Stkeholders collaboration	0.065252	0.157936
	Environment strategy alliances	0.111496	0.269865
	Coordination with outside institutes	0.056698	0.137232
	Market adaption	0.042615	0.103145
Human organization capacity	Human quality	0.080414	0.339906
	Human management	0.037417	0.158160
	Organization culture establishment	0.048812	0.206326
	Organization operation management	0.025564	0.108058
	Continuous improvement	0.044370	0.187550

Matrix like W_{ij} are grouped and placed in the appropriate positions in a supermatrix based on the flow of influence from one cluster to another or from a cluster to itself, forming a loop. Here is unweighted supermatrix under each criteria:

$$W = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1N} \\ w_{21} & w_{22} & \cdots & w_{2N} \\ \cdots & \cdots & & \cdots \\ w_{N1} & w_{N2} & \cdots & w_{NN} \end{bmatrix}$$

Then comparing each cluster with respect to their importance indirectly towards the criteria, the normalized eigenvector of comparison matrix feature vectors can be calculated and pairwise comparison matrix A is obtained:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ a_{21} & a_{22} & \cdots & a_{2N} \\ \cdots & \cdots & & \cdots \\ a_{N1} & a_{N2} & \cdots & a_{NN} \end{bmatrix}$$

The weighted super matrix provides the value that obtained by the super matrix values and the value of each cluster, the elements in $\bar{W}$ are the weight in the system found by solving the following equation:

$$\bar{W} = a_{ij}W_{ij},\ i = 1, 2,..., N, \qquad j = 1, 2,..., N$$

Finally, the limit supermatrix has the same form as the weighted supermatrix but all columns of the limit supermatrix are the same. In the limit matrix, the constant values of each value are determined by taking the necessary limit of the weighted super matrix.

The results: According to pairwise comparison and super-matrix calculation, the limiting priorities and normalized by cluster priorities using super decision software were given in Table 3. It shows that High-cost CP alternative got the priority of 45.2366%, followed by Low-cost one (38.1142%) and the Mid-cost got lest weigh of 16.6492%, which implies the most preferable alternative is high-cost that can produce most profit for improving the environmental performance. The second preferable one is Low-cost that mostly invests in non-technic activities. The alternative of Mid-cost is the unreasonable one with less profit. The result suits enterprises' CP capacity, that is, the construction companies will participate in improvement of technic or human capacity, such as technic innovation and human quality (High-cost) and environment strategy alliances and organizational culture (Low-cost).

CONCLUSIONS

This study suggests a decision-making model for selection of CP alternation on basis of enterprises' capacity in construction industry, which considers interdependencies among elements and clusters constituting a complex network. This study applied ANP approach to avoid the mistakes caused by assuming all clusters are independent. This results implied several things: first, construction company should consider participating into High-cost CP option that can advance environmental development.

Second, company tends to adopt Low-cost option is not best choice, because it is difficult to finish CP efficiencies for the complication of construction enterprise. Third, Mid-cost one will slow the speed to develop CP strategy. The result show that decision-making model can provide a scientific, effective and reasonable basis on the enterprises' characters.

Further research is need to do, because there are a number of shortages, such as: The qualitative indicators mostly depend on the subjective thought; The quantitative indicators lack a most effective approaches to integrate judgments; Finally, it is difficult to correctly sort these indicator without real cases. In addition to these, more research and problems needed us to do further work, which make decision-making work more effectively in CP option selection of construction industry.

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