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Evaluation of Construction Green Supply Chain Management

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Abstract. The green supply chain management (GSCM) is a powerful way to differentiate a company from its competitors and it can heavily influence the project success. This study aims to evaluate GSCM practice implementation among contractors. GSCM is an intangible and vague concept that is difficult to measure. The fuzzy analytic hierarchy process (FAHP) is adopted to determine the relative weights linking each independent variable. Neurofuzzy system (NFS) using ANFIS method is used to evaluate GSCM. Fuzzy computation is applied to address the human subjectivity in the evaluating process which is usually vague and imprecise. Furthermore, the illustrative application of the proposed framework is provided through expert opinions to show the evaluation of GSCM. The results show that green purchasing and internal environmental management are the most important construct of GSCM. The weights associated with aspects, criteria, and sub-criteria of GSCM may suggest how the companies can achieve competitive advantage by enhancing the GSCM.

Keywords: green supply chain, Adaptive Neuro Fuzzy Inference System (ANFIS)

1. Introduction

Supply chain management has the potential to make construction projects less fragmented, improve project quality, reduce project duration, and hence reduce total project cost, while creating more satisfied customers. The green supply chain management (GSCM) has emerged as an effective management tool and philosophy for proactive and leading construction organizations. The scope of GSCM practices implementation ranges from green purchasing (GP) to integrated life-cycle management supply chains flowing from supplier, through to contractor, customer, and closing the loop with reverse logistics. Prescriptive models for measures of GSCM practices implementation with a focus on GP and GSCM have been developed. [1] developed a decision model to measure environmental practice of suppliers using a multiattribute utility theory approach. [2] proposed the multiple attribute utility theory method for assessing a supply chain including re-use and recycling throughout the life cycle of products and services. Using the tool of life-cycle assessment, [3] put forward aspects to measure GSCM practices implementation, that is, materials acquisition, preproduction, production, use, distribution, and disposal. [4] developed a linear multi-objective programming model that optimized the operations of both forward and reverse logistics in a given green supply chain. These models and frameworks included and defined a variety of characteristics, attributes, and scales for GSCM practices implementation, yet none attempted to rigorously validate these scales. After embracing green supply chain (GSC) an important question must be asked: How construction companies can answer how green is supply chains? This evaluation is essential for construction managers as it assists in achieving GSC effectively by performing gap analysis between existent environmentally sustainable level and the desired one and also provides more informative and reliable information for decision making. Therefore, this study attempts to answer this question with a particular focus on measuring GSCM.

A procedure with aforementioned functionality must be develop to cope with uncertain environment of construction projects and lack of efficient measuring tool for sustainability of supply chain system. The fuzzy analytic hierarchy process (FAHP) is adopted to determine the relative weights linking the construct of

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GSCM. This study is to apply fuzzy concepts and aggregate this powerful tool with Artificial Neural Network concepts in favor of gaining ANFIS to handle the imprecise nature of attributes for associated concepts of sustainability. ANFIS is considered as an efficient tool for development and surveying of the novel procedure. The combination between FAHP and ANFIS has never been reported in literature before.

2. Construction Supply Chain

2.1. Construction supply chain

Considering the construction industry, the client represents a unique customer with unique requirements. Stakeholders in the supply chain will provide these requirements. They must have the required primary competencies to make possible the fulfilment of these requirements. In reality, organisations within a supply network delivering an office development will differ from those required to deliver a residential project. It may be useful to consider the chain as a network of organisations or a network organisations operating within the same market or industry to satisfy a variety of clients. Stakeholders involved in the construction supply-chain were classified into five categories related to the construction stages [5]. The contract is the predominant approach for managing the relationship between organisations that operate in a construction project to deliver the client's required project. Although contracts are a sufficient basis for the delivery of a completed project, they are not sufficient to deliver a construction efficiently, at minimum cost, and right first time'.

2.2. Green supply chain

As a synergistic joining of environmental and supply chain management, the competitive and global dimensions of these two topics cannot go unnoticed by construction organizations. Simultaneously, due to stricter regulations and increased community and consumer pressures, manufacturers need to effectively integrate environmental concerns into their regular practices and onto their strategic planning agenda. As a result, integrating environmental concerns into supply chain management has become increasingly important for contractors to gain and maintain competitive advantage. Sustainability is defined in several ways. Similar to the concept of supply chain management, the boundary of GSCM is dependent on researcher goals and the problems at hand. [6] considered stages that GSCM should be implemented. The definition of sustainability is still fuzzy, mainly because it largely deals with things already being addressed by industry and which are covered by existing research projects and programs. [7] introduced a set of quantitative indicators to formalize the appraisal process for GSCM evaluation. The indicators can be classified into five categories including 1) Internal environmental management (IEM), 2) Green purchasing (GP), 3) Cooperation with customers (CC), 4) Eco-design (ECO), and 5) Investment recovery (IR). There are twenty-one criteria identified from the literature. The 21 criteria included 1) Commitment of GSCM from senior managers (IEM1), 2) Support for GSCM from mid-level managers (IEM2), 3) Cross-functional cooperation for environmental improvements (IEM3), 4) Total quality environmental management (IEM4), 5) Environmental compliance and auditing programs (IEM5), 6) ISO 14001 certification (IEM6), 7) Environmental Management Systems exist (IEM7), 8) Eco labeling of products (GP1), 9) Cooperation with suppliers for environmental objectives (GP2), 10) Environmental audit for suppliers' internal management (GP3), 11) Suppliers' ISO14000 certification (GP4), 12) Second-tier supplier environmentally friendly practice evaluation (GP5), 13) Cooperation with customers for eco design (CC1), 14) Cooperation with customers for cleaner production (CC2), 15) Cooperation with customers for green packaging (CC3), 16) Design of products for reduced consumption of material/energy (ECO1), 17) Design of products for reuse, recycle, recovery of material, component parts (ECO2), 18) Design of products to avoid or reduce use of hazardous products and/or their manufacturing process (ECO3), 19) Investment recovery (sale) of excess inventories/materials (IR1), 20) Sale of scrap and used materials (IR2), and 21) Sale of excess capital equipment (IR3). The aggregation of current approaches can be criticized as they haven't considered the impact of enablers in assessing sustainability in supply chains and also the scale used to aggregate the performance of the construct of GSCM has the limitations. The first limitation is that the techniques do not consider the ambiguity and multi possibility associated with mapping of individual judgment to a number. The second limitation is the subjective judgment, selection and preference of evaluators having a significant influence on these methods. Because of the fact that the qualitative and ambiguous attributes are linked to sustainability assessment, most measures are described subjectively using linguistic terms, and cannot be handled effectively using conventional assessment approaches. The fuzzy logic provides an effective means of handling problems involving imprecise and vague phenomena. Fuzzy concepts enable assessors to use linguistic terms to assess indicators in natural language expressions, and each linguistic term can be associated with a membership function. In addition, fuzzy logic has generally found significant applications in management decisions [8]. This study applies a fuzzy analytic hierarchy process (FAHP) to determine the relative weights linking each independent variable. The variables with high weighting score are selected. A fuzzy inference system is used for mapping input space (tangible and intangible) to output space in order to assist construction companies in better achieving an sustainability supply chain. The proposed Fuzzy Inference System (FIS) has been based on the experiences of experts to evaluate sustainability of construction supply chains.

3. Methodology

To evaluate sustainability of the construction supply chain two main steps are performed. At the first step, measurement criteria are identified. A conceptual model is developed based on literature review. This study used a framework for evaluation of GSCM proposed by [7] to identify criteria for GSCM evaluation. Twenty one sub-attributes are the basis of the conceptual model as shown in Table 1. At the Second step, the design of an ANFIS architecture is performed by constructing an input-output mapping based on both human knowledge in the form of fuzzy if-then rules with appropriate membership functions and stipulated input-output data based- for deriving sustainability in supply chains.

4. FAHP

This section provides an overview of a fuzzy analytic hierarchy process (FAHP) for addressing uncertainty in the particular assessment. The fuzzy pairwise comparison considers favorable and adverse effects of uncertainty. Fuzzy numbers are used to present uncertainty involved in the pairwise comparisons by using parameters l and u to present favorable and adverse effects of uncertainty, respectively. [9] proposed the FAHP, which is one of the effective approaches used to address the uncertainty and vagueness from the subjective perception and the experience of humans in decision-making process. Therefore, the opinions of decision makers are converted from previous definite values to fuzzy numbers and membership numbers in FAHP, so as to present in FAHP matrix. [10] suggests that the fuzzy AHP is an appropriate approach for overcoming difficulties in explicitly expressing the decision maker's preference involved in the comparison process. By using the fuzzy AHP, the decision makers are allowed to provide the comparing results by the interval judgement instead of crisp value judgement which makes the decision makers feel more convenient and confident. The effects of uncertainty on the pairwise comparison are qualitatively estimated by the decision maker at a given level regarding their parent in the next higher level, based on the requirement of the comparative judgement principle. The fuzzy AHP integrates these individual effects of uncertainty on the pairwise comparison by combining the calculated ratio-score local priorities according to the requirement of the synthesis of priorities.

Currently, fuzzy AHP has been applied to the selection of software development strategy, the evaluation of government websites, and the selection of global suppliers [11]. Assessors are asked to qualitatively estimate the level of impact that each affecting factor or a set of affecting factors has on the comparison of a pair of elements. It is believed that this approach of qualitative comparison is practical because the impacts of uncertainty are easily expressed in linguistic terms [12]. There is no inherent restriction on the number of levels of impacts used for each affecting factor or a set of affecting factors. This study applies fuzzy AHP to evaluate the weight factor by using five linguistic terms: equally significant, moderately significant, strongly significant, very strongly significant, and extremely significant of which the numerical ratings are 1, 3, 5, 7, and 9, respectively (data from [8]).

5. Neuro-Fuzzy Model

The neuro-fuzzy system attempts to model the uncertainty in the factor assessments, accounting for their qualitative nature. A combination of classic stochastic simulations and fuzzy logic operations on the ANN inputs as a supplement to artificial neural network is employed. Artificial Neural Networks (ANN) has the capability of self-learning, while fuzzy logic inference system (FLIS) is capable of dealing with fuzzy language information and simulating judgment and decision making of the human brain. It is currently the research focus to combine ANN with FLIS to produce fuzzy network system. ANFIS is an example of such a readily available system, which uses ANN to accomplish fuzzification, fuzzy inference and defuzzification of a fuzzy system. ANFIS utilizes ANN's learning mechanisms to draw rules from input and output data pairs. The system possesses not only the function of adaptive learning but also the function of fuzzy information describing and processing, and judgment and decision making. ANFIS is different from ANN in that ANN uses the connection weights to describe a system while ANFIS uses fuzzy language rules from fuzzy inference to describe a system.

The ANFIS approach adopts Gaussian functions (or other membership functions) for fuzzy sets, linear functions for the rule outputs, and Sugeno's inference mechanism [13]. The parameters of the network are the mean and standard deviation of the membership functions (antecedent parameters) and the coefficients of the output linear functions as well (consequent parameters). The ANFIS learning algorithm is then used to obtain these parameters. This learning algorithm is a hybrid algorithm consisting of the gradient descent and the least-squares estimate. Using this hybrid algorithm, the rule parameters are recursively updated until an acceptable level of error is reached. Each iteration includes two passes, forward and backward. In the forward pass, the antecedent parameters are fixed and the consequent parameters are obtained using the linear least-squares estimation. In the backward pass, the consequent parameters are fixed and the error signals propagate backward as well as the antecedent parameters are updated by the gradient descent method. An ANFIS architecture is equivalent to a two-input first-order Sugeno fuzzy model with nine rules, where each input is assumed to have three associated membership functions (MFs) [14]. Sub-attributes associated with flexibility, responsiveness & quickness, competency and cost are used as input variables; simultaneously, construction supply chain sustainability is considered as output variables. These input variables were used in the measurement of the supply chain sustainability by Jassbi, et.al (2010) [15].

The performance the proposed method is tested by using the fifteen scenarios. The results indicate that the output values obtained from ANFIS are closer to the values given by experts in most scenarios being tested. For the main model, the average and standard deviation of the differences between the estimated and the output values obtained from expert produced by ANFIS are calculated to be 18.3% and 11.5% respectively. For the five sub-models, the average and standard values are smaller than the ones obtained from the main model.

Table 1: input/output indicators

Main model		Sub-model	
Output	Input	Output	Input
	Criteria		Sub-criteria
Environmental performance regarding GSCM implementation	Internal environmental management (IEM)		1. Commitment of GSCM from senior managers (IEM1) 2. Support for GSCM from mid-level managers (IEM2) 3. Cross-functional cooperation for environmental improvements (IEM3) 4. Total quality environmental management (IEM4) 5. Environmental compliance and auditing programs (IEM5) 6. ISO 14001 certification (IEM6) 7. Environmental Management Systems exist (IEM7)
	Green purchasing (GP)		8. Eco labeling of products (GP1) 9. Cooperation with suppliers for environmental objectives (GP2) 10. Environmental audit for suppliers' internal management (GP3) 11. Suppliers' ISO14000 certification (GP4) 12. Second-tier supplier environmentally friendly practice evaluation (GP5)
	Cooperation with customers (CC)		13. Cooperation with customers for eco design (CC1) 14. Cooperation with customers for cleaner production (CC2) 15. Cooperation with customers for green packaging (CC3)
	Eco-design (ECO)		16. Design of products for reduced consumption of material/energy (ECO1) 17. Design of products for reuse, recycle, recovery of material, component parts (ECO2) 18. Design of products to avoid or reduce use of hazardous products and/or their manufacturing process (ECO3)
	Investment recovery (IR)		19. Investment recovery (sale) of excess inventories/materials (IR1) 20. Sale of scrap and used materials (IR2) 21. Sale of excess capital equipment (IR3)

6. Conclusion

This paper has discussed the need for sustainability assessment of the construction supply chain. The particular features of construction supply chains highlighted. The need for and potential benefits of the evaluation of GSCM were then examined and the conceptual model of a GSCM evaluation model for the construction supply chain presented. Case studies of the use of the model in assessing the construction organizations were presented. The following conclusions can be drawn from the work presented in this paper: The way to improve the construction supply chain delivers projects is necessary to achieve client satisfaction, ecological efficiency, effectiveness, and profitability. It is important to perform the evaluation of GSCM in order to ensure that effective joining of environmental and supply chain management can be obtained. Since the competitive and global dimensions of GSCM are important, evaluating supply chain sustainability can be useful and applicable for managers to make more informative and reliable decisions in anticipated changes of construction markets. The development of an appropriate GSCM evaluation model for the construction supply chain is necessary. The results reveal that the integration between FAHP and ANFIS model improves GSCM evaluation. The selection of the important aspects can be well performed by using FAHP. The ANFIS model can explain the training procedure of outcome and how to simulate the rules for evaluation.

7. References

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