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Implementation and Performance Evaluation of a Firm's Green Supply Chain Management under Uncertainty

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ABSTRACT

Evaluation of the implementation and performance of a firm's green supply chain management (GSCM) is an ongoing process. Balanced scorecard is a multi-criteria evaluation concept that highlights implementation and performance measures. The literature on the framework is abundant literature but scarce on how to build a hierarchical framework under uncertainty with dependence relations. Hence, this study proposes a hybrid approach, which includes applied interpretive structural modeling to build a hierarchical structure and uses the analytic network process to analyze the dependence relations. Additionally, this study applies the fuzzy set theory to determine linguistic preferences. Twenty dependence criteria are evaluated for a GSCM implemented firm in Taiwan. The result shows that the financial aspect and life cycle assessment are the most important performance and weighted criteria.

Keywords: Green Supply Chain Management, Fuzzy Set Theory, Balanced Scorecard, Analytic Network Process, Interpretive Structural Modeling

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1. INTRODUCTION

There is a lack of operation of related concepts for implementation and performance of green supply chain management (GSCM) in a firm with balanced scorecard (BSC) measures in the hierarchical structure. Without this, we cannot find empirically whether it actually implements these inter-firms' green activities and whether these activities, in turn, affect performance outcomes. More importantly, there is a limited amount of research that simultaneously evaluates the firm's implementation and performance perspectives of the GSCM issues. This study draws on both perspectives to validate their implementation plan and performance level on firm's GSCM. There are even fewer studies that address the hierarchical structural-building and dependence relations of the BSC in qualitative measures, to perform measurements on GSCM activities and to make an implementation in a manufacturing firm.

The electronic industry has experienced increasing environment consciousness, has achieved waste elimination and has reduced its impact on the environment. This progress has resulted from the European Union's establishment of a range of environmental policies. GSCM has emerged as an approach to balance these environmental requirements. A firm's management must balance efforts to reduce costs and innovate while maintaining good environmental performance (Pagell *et al*., 2004). However, the GSCM implementation and performance evaluation of an OEM firm is an on-going process that requires continuous monitoring to maintain a high level of internal process evaluations across a number of criteria in an organization. In terms of internal process evaluation, the BSC is well-recognized in the literature because measures should incorporate both financial and non-financial criteria; the BSC captures not only a firm's current implementation, but also the drivers of its future performance (Banker and Datar, 1989; Dyson, 2000). There are fewer studies of the development and implementation of the BSC when measuring the performance of the GSCM. Hence, there are BSC studies on other industries, such as banking, textile, and pharmaceuticals (Bremser and Barsky, 2004; Cebeci, 2009; Wu *et al*., 2009).

The GSCM framework has been widely accepted in the industrial community; the best method for implementing the framework remains an issue. In addition, the BSC is a model for the analysis of a firm's performance measurement and reward system for all types of organizations (Kaplan and Norton, 1992). The BSC is an important activity that helps organizations make continuous improvements because of its strong emphasis on performance measurement. It has been developed to integrate the performance measurement system with the organizational goal, and aligns production, marketing, organization process, non-financial and traditional functions with firm strategies using performance criteria (leading indicators) and outcome measures. Firms can evaluate their management in terms of their effectiveness at creating value for customers, developing internal capabilities, and investing in the people and systems that are necessary to improve their future performance. These activities imply that there are dependence relations that exist in the BSC framework. However, the traditional statistical approach is no longer suited to evaluate a proposed network BSC because the traditional approach assumes that the aspects and criteria are always independent. The firm's GSCM evaluation-related activities have inherent and high uncertainty and imprecision and are difficult to assess accurately with qualitative information.

Previous BSC studies, such as Wang *et al*. (2010), proposed a model developed for measuring the acceptable performance of case firms based on the BSC perspectives. The hierarchical structure integrated with non-additive fuzzy integral for designing, developing and implementing high technology firms relevant to performance measurement was employed to overcome interaction among the various perspectives. Moreover, Chen *et al*. (2011) used BSC approach to an effective technique for performance evaluation to reflect the dependence and feedback problems among criteria. Fu and Yang (2012) proposed the dependence-based interval-valued evidential reasoning (DIER) performance measurement approach can model multiple attribute decision analysis problems with both quantitative and qualitative attributes under the uncertain environment and uses of BSC perspectives with the combination of DIER approach. However, none of these studies consider the hierarchical structure or the nature of the dependences among the criteria. This study proposes to employ the analytical network process (ANP) technique to approach the proposed BSC with dependence relations. ANP is a technique that takes into account the feedback and dependence relations among the proposed criteria (Saaty, 1996). The most important merit is to provide a more generalized model for decision-making without making assumptions about the independence relationships among the proposed criteria.

In view of qualitative measures (uncertainty), the fuzzy set theory usually addressed the situations lacking well-defined boundaries of activity or observation sets (Zadeh, 1965, 1975). In practical cases, human preferences are uncertain and qualitatively expressed and uneasy to assign exact values to precisely describe their preferences. Linguistic terms have been used for approximate reasoning within the framework of fuzzy set theory to handle the ambiguity of evaluating data and the vagueness of linguistic expression. Hence, the fuzzy set theory can express and handle vague or imprecise judgments mathematically (Al-Najjar and Alsyouf, 2003; Lin *et al*., 2013; Tseng and Lin, 2009). Usually, linguistic preferences are used to evaluate aspects or criteria that have values that are not numbers but instead are linguistic preferences. The linguistic values can be represented by triangular fuzzy numbers (TFNs), which is commonly used in representing the linguistic terms. Moreover, the quantitative measures should transform into comparable crisp values to compare with all of the qualitative measures. This study adopts the interpretive structural modeling (ISM), fuzzy set theory and ANPs to assess BSC in the assessment of a firm's GSCM measures.

This study addresses two important and related perspectives in the implementation of a BSC—the handling of the dependences among the criteria, especially those of a qualitative nature, and the transformation of crisp values—to compare with other measures and to determine the contribution of the respective criteria. In view of the respective advantages of the proposed methods, this study attempts to propose a hybrid approach to evaluate the assessment of GSCM performance evaluation. The rationale of the proposed approach is to combine the ISM, fuzzy set theory and the ANP method into one system, in which ISM builds a hierarchical structure, the fuzzy set theory accounts for the linguistic vagueness of the qualitative criteria, and the ANP converts the dependence relationships in the hierarchical structure into intelligible weights (Tseng, 2010, 2013). The aim of this study is to propose a hybrid approach to a firm's GSCM implementation and performance, which requires a hierarchical structure and dependence analysis under uncertain conditions. In this study, BSC performance evaluation for an OEM firm in Taiwan will be evaluated. Moreover, the hierarchical structure must be built by the dependence criteria; the uncertainty is mainly the result of rapid changes in marketing information and human perceptions, while the dependences are mainly from the various criteria of the system.

The remainder of this study is organized as follows. Section 2 surveys the related work in the literature. Section 3 presents the proposed approach. Section 4 subsequently applies the proposed approach to evaluating a case study of a firm. The results are presented in Section 5, which is followed by a discussion of the managerial implications and conclusions in Section 6.

2. THEORETICAL BACKGROUND

GSCM criteria have been applied to control materials, to control the flow of information and to develop green strategies. The criteria on firms' level are to describe the quality of strategic direction, inter-organization and internal service and to address green suppliers and prospective consumers, all to improve their competitiveness in competitive market. Moreover, The definition of GSCM is "*the set of supply chain management policies held, actions taken and relationships formed in response to concerns related to the natural environment with regard to the design, acquisition, production, distribution, use, re-use and disposal of the firm's goods and services*" (Zsidisin and Siferd, 2001). The growth in GSCM literature extends back to the early 1990s with the advent of corporate environmental management, environmentally conscious manufacturing strategy, and SCM literature (Sarkis, 1998). A number of literatures referred to the over the past decade discusses as follows.

2.1 Rationale of Study

The GSCM activities of firms are related to green products and production environmental processes as well as to the selection of eco-materials. The customers' requirements are often blended with the concepts of the green supply chain; thus, they typically focus on the immediate outcome of the supplier and on the methods that are used to achieve green operations and products. Moreover, collaborations between the firm and upstream suppliers can take place simultaneously (Zhu and Sarkis, 2004). GSCM advocates efficiency and synergy between partners and facilitates environmental performance, minimal waste and cost savings. Environmental management covers from product development to final delivery and ultimate disposal of the product and take into the context of environmental and financial benefits included reduction, recycling, reuse and the substitution of materials (Green *et al*., 1996; Klassen and Whybark, 1999). The results have shown that a higher degree of integration between suppliers and customers in the supply chain results in a greater competitive advantage.

A recent study conducted by Zhu *et al*. (2008) investigated the models of GSCM practices, the empirical results suggested the management support for idea and practices should be from top and middle-level management across to whole organizational functions and enhance organizational learning mechanisms after understanding for a number of other influences including regulations, marketing, supplier, cost pressures and relevant practices. In addition, Tseng (2011) addressed that as firms move toward sustainability, management must extend their efforts to improve green practices across the supply chain. The selection of a suitable green supplier according to GSCM is essential for the sustainable development of manufacturing firms. Tseng's approach is in the presence of fuzzy set theory and grey relational analysis to present the system information lacking and uncertainty together. This collaboration focuses on inter-organizational interactions between suppliers and manufacturing firm environmental goal setting and planning. The results indicated that upstream practices were more closely linked with process-based performance, while it was associated with product-based performance.

In addition, Diabata and Govindan (2011) implied that the green design, integrating quality environmental management into planning and operation process, reducing energy consumption, and reusing and recycling materials and packaging drivers needed to be placed in first prioritization. Moreover, the results suggested that firms focused on hierarchical framework could deploy a collection of resources, enabling the firm to successfully compete against rivals. Hence, an intensive review of knowledge was conducted to provide valuable information that can help manufacturing firms increase their competitive advantage. However, Linton *et al.* (2007) showed that the research and practice in SCM can affect policy, science or social science by presenting alternative scenarios for the development of sustainable supply chains. Sustainability stretches the concept of SCM to look at optimizing operations from a broader perspective—the entire production system and post production stewardship as opposed to just the production of a specific product. GSCM activities have been practiced in the industry for a few years. There is a need for performance and implementation evaluations to be conducted because no studies have considered firm evaluations.

Hence, there are many activities that must be addressed in a firm's GSCM. Hence, using BSC approach takes into consideration the organization's vision and strategies and focuses on both financial and non-financial performance. In short, this study monitors short-term financial performance while also highlighting the value of implementation activities and competitiveness.

2.2 Proposed GSCM Criteria

Contributions from industry and academia were used to establish twenty criteria for the implementation and performance evaluation of a firm's GSCM (Li *et al*., 2006; Tseng *et al*., 2008). The GSCM requires a set of criteria, which include information regarding the financial aspect, customer aspect, internal operations aspect and learning and growth aspect of a firm. The performance evaluation is a systematic review process carried out to help an organization reach a certain goal. Making performance evaluation part of the management and control system helps the organization to effectively manage its resources and measure its performance in relation to its goals (Wu and Hung, 2008). Pinero (2001) the balanced scorecard approach is aimed at helping the organization achieves its goals, while maintaining the traditional financial perspective to measure its tangible assets. It includes three perspectives (i.e., customers, internal processes, and learning and growth) to evaluate intangible assets and intellectual capital. Organizational strategies are examined from both financial and non-financial perspectives, based on actual data for a comprehensive evaluation. However, a firm's GSCM must have outstanding competitive advantages to perform well in the internal operations process, such as innovation of green products measures with excellent conformance quality on green products. These activities are closely related to top management support that requires annual growth in green products. As such, the present study will view a complex, interactive process of many different resources with multi-dimensional, interdependent GSCM criteria (Sarkis, 1998; Tseng *et al*., 2008).

To ensure that annual growth in green products, the customer retention and percentage of growth with existing customers are an important part of the firm's financial practices (Harland *et al*., 1999; Yao *et al*., 2007). Hence, customer satisfaction is defined as "*the ability to meet customer demand and the ability to react quickly to customer orders is critical to improving the firm's customer service, which includes customer retention, customer acquisition, service quality and Industry leadership.*" Johnston *et al*. (2004) explored customer and supplier relationships, linking the supplier's level of trust to inter-firm cooperative behaviors and presents higher levels of inter-organizational cooperative behaviors, such as shared planning and flexibility in coordinating activities, were found to be strongly linked to the supplier's trust in the customer's purchasing, quality, customer relations and relationship supplier closeness to evaluate the suitability of a supplier selection model. Dreyer and Gronhaug (2004) pointed supplier capabilities for green products are a complex and multi-dimensional type of capabilities that requires firm-wide efforts to increase a firm's responsiveness, to reduce waste and to limit the firm's environmental impact. Despite much discussion about the need for enhancing the financial performance and marketing development in customer-supplier alliances, there is a paucity of empirical evidence showing that GSCM evaluation really has any impact on the performance of inter-firm green activities.

In order to approach the environmental business practices, the life cycle assessments (LCA), the total quality of environmental management and compliance with environmental standards to reduce of hazardous materials in the operational process (Sarkis, 1998). Zhu and Geng (2001) studied Chinese firms and examined their methods of environmental development in business practices utilized LCA, ISO14000, environmental management system, etc. In addition, LCA is a tool for analyzing environmental impacts in a wide perspective, such as all the activities needed in the production, use and disposal of a product. Even though LCAs are mainly done for products, it is possible to perform an LCA for any system of economic activity. Researchers have included internal green production and the quality of internal service as GSCM criteria, and the supplier's purchasing perspective has also been addressed (Harland *et al*., 1999; Stanley and Wisner, 2001).

Sustainability provides an overarching framework for much of the past and ongoing environmental studies in operations and moves beyond current common practice in the industry. Supply chains must be explicitly extended to include by products in the supply chain, to consider the entire lifecycle of the product, and to optimize the product not only from a current cost standpoint but also a total cost standpoint. Total cost must include the effects of resource depletion and the generation of by products that are neither captured nor used (hazardous and waste in operations process). Research into the operational implications of various policies and how business can integrate sustainability is critical, since current legal trends force many of these changes whether or not academe and practice is prepared.

GSCM capabilities are "*complex bundles of individual skills, employee capabilities, assets and accumulated knowledge that are exercised through production processes and that enable firms to co-ordinate activities and to make use of their resources*" (Zhu and Sarkis, 2004). This discussion is proven that there are complex dependence relations among the proposed criteria. In summary, this study uses twenty criteria on qualitative and quantitative scales to evaluate a firm's GSCM under uncertain conditions. Table 1 presents the firm's GSCM approach to supplier selection.

3. METHOD

In view of the complexity of the dependences, the evaluation of the firm's GSCMs for their performance

Table 1. Evaluation of firms' GSCM approach

Criteria
Annual growth in green products (C1) (past 3 years data)
Cost of revenue: extent that it remains flat or decreases each year (C2)
Profit margin: return on total capital employed (C3) (past 3 years data)
Growth from new green products per year (C4) (past 3 years data)
Industry leadership: green market share (C5)
Customer retention/percentage of growth with existing customers (C6)
Customer acquisition: number of new green customers/total revenue to new green customers (C7) (past 3 years data)
Customer satisfaction on green products (C8)
Customer/supplier profitability on green products (C9)
Service quality: customer/supplier complain rates (C10)
Top management support on green issues (C11)
The reduction of hazardous materials in the production process; (C12)
Green purchasing capabilities/design/production (C13)
Life cycle assessment (C14)
Environmental management systems (C15)
Innovation of green products measures (C16)
Rate of new green product introduction per year (C17) (past 3 years data)
Employee capabilities (C18)
Internal green production plans (C19)
Conformance quality on green products (C20)

The criteria are with dependence relations and self-feedback.
GSCM: green supply chain management.

and implementation would be expected to have multi-dimensional difficulties, and the building of a hierarchical framework is lacking in prior studies. As discussed in the previous section, the criteria cluster includes dependence relations to precisely find out the best supplier among the four suppliers of the case study firm. Overall, the BSC criteria of the case study firm (Suppliers A, B, C, D) can be obtained by 1) assigning weights to associated criteria (C_{ij}, i = 1, 2, 3, 4 ⋯, C_i, j = 1, 2, ⋯, C_j) and 2) assessing the performance rating of each aspect and its associated criteria. This section first introduces ISM, fuzzy set theory and ANP technique followed by the proposed application procedures.

3.1 Transform the Quantitative Data

The quantitative (crisp) numbers of criteria have varying units that cannot be compared. The crisp value numbers must be normalized to achieve criteria values that are unit-free and therefore comparable. The normalized crisp values of C_{ij} calculated following Eq. (1) (Tseng *et al*., 2009).

$$\mathrm{C_{ij}} = \frac{c_{ij}^N - \min c_{ij}^N}{\max c_{ij}^N - \min c_{ij}^N}, \quad C_{ij} \in [0, 1]; N = 1, 2, \cdots, n \quad (1)$$

where $\max C_{ij}^N = \max\{c_{ij}^1, c_{ij}^2, \cdots, c_{ij}^N\}$ and $\min C_{ij}^N = \min\{c_{ij}^1, c_{ij}^2, \cdots, c_{ij}^N\}$.

3.2 Fuzzy Set Theory

Fuzzy set theory (Zadeh, 1965) is a mathematical theory that is designed to model the fuzziness of human cognitive processes. The membership function $\mu_A(x)$ of a fuzzy set operates over the range of real numbers, generally scaled to the interval [0, 1]. An uncertain judgment can be represented by a fuzzy number. TFNs is a special type of fuzzy number that has a membership function that is defined by three real numbers (*l, m, u*), provided that $l \le m \le u$. This membership function is illustrated and described mathematically below (Lin *et al*., 2010; Pan, 2008; Tseng, 2010). Triangular fuzzy membership functions are presented as follows.

A TFN A can be defined as a triplet (*l, m, u*), and the membership function is defined as:

$$A(a) = \begin{cases} 0, & a < l \\ (a-l)/(m-l), & l \le a \le m \\ (u-x)/(u-m), & m \le a \le u \\ 0, & a > u \end{cases} \quad (2)$$

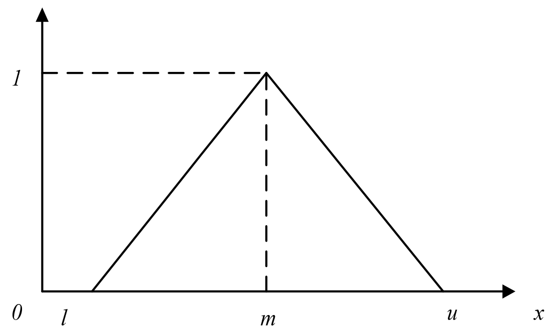

Figure 1. Triangular fuzzy number $A = (l, m, u)$.

Table 2. Linguistic scales for the important weight of criteria

Linguistic variable	TFNs
No important	(0, 0.1, 0.3)
Very low important	(0.2, 0.3, 0.5)
Low important	(0.3, 0.5, 0.7)
High important	(0.5, 0.7, 0.9)
Very high important	(0.7, 0.9, 1.0)

This table is the linguistic scale and their corresponding TFNs.
TFN: triangular fuzzy number.

where l, m, and u are real numbers and $l \le m \le u$ (Figure 1).

Therefore, l, m, u represent the lower, mean, and upper bounds of the TFN, respectively. The membership function represents the degree to which any given element x in the domain X belongs to a fuzzy number A. To address linguistic preferences, linguistic variables have been defined for several levels of preferences. The TFNs used to represent these preferences are depicted in Table 2.

A fuzzy weighted sum performance matrix (P) can be derived for specific criteria by multiplying the fuzzy weight vector related to the criteria with the decision matrix for the criteria.

$$P = \begin{bmatrix} \begin{pmatrix} l_1, & m_1, & u_1 \\ \cdots & \cdots & \cdots \\ l_n, & m_n, & u_n \end{pmatrix} \end{bmatrix} \tag{3}$$

where n represents the number of criteria. The defuzzification method, according to Pan (2008), uses TFNs. The TFNs can be applied to transform the total weighted performance matrices into interval performance matrices, which provide a_l and a_u for each criterion, as follows:

$$p_a = \begin{bmatrix} \begin{pmatrix} a_{l1}, & a_{m1}, & a_{u1} \\ \cdots & \cdots & \cdots \\ a_{ln}, & a_{mn}, & a_{un} \end{pmatrix} \end{bmatrix} \tag{4}$$

where n is the number of criteria.

$$\begin{cases} a_l = l \times (m - l) + l \\ a_u = u - l \times (u - m) \end{cases} \tag{5}$$

This procedure is performed by applying the Lambda function, which also represents the attitude of the evaluator. Evaluators with optimistic, moderate and pessimistic attitudes take on maximum, intermediate, or minimum Lambda values in the range [0, 1], respectively:

$$C_\varepsilon = \begin{pmatrix} W_j^1 \\ W_j^2 \\ \cdots \\ W_j^k \end{pmatrix} \tag{6}$$

$$C_\varepsilon = \lambda \times a_u + (1 - \lambda) \times a_l \tag{7}$$

where the C_ε are crisp values corresponding to epsilon. These values should be normalized to acquire comparable scales.

3.3 Interpretive Structural Modeling

The concept and detailed methodology of ISM was first introduced by Warfield (1974) as a computer-assisted methodology to identify and construct the inter-relationships of different elements within a complex system or issue. The most remarkable contribution of this method is to provide a systemic insight of a complicated system through graphics and words. Hence, ISM has been widely used to effectively identify and understand the mutual influences among specific criteria within an issue.

The initial step begins with the identification of relevant criteria using group problem-solving techniques, and then a structural self-interaction matrix is developed to indicate pair-wise relations of suggested criteria. After that, this relation matrix is converted into the reachability matrix by transforming the information in each entry of the linguistic preferences into 1s and 0s (Argawal *et al.*, 2007). The next step is the partitioning of the criteria into different levels that are based on assessing the reachability and antecedent sets for each criterion, followed by the development of the interactive matrix. The matrix is converted into a hierarchical model by replacing the criteria nodes with statements. The extracted structural model is reviewed to check for conceptual inconsistencies and needed modifications (Singh *et al.*, 2003).

In the model, the criteria of the system are represented by the "*points*" of the graph; simultaneously, the relations among criteria are indicated by a directed line segment. This concept of relatedness regarding a specific relation obviously distinguishes this method from a mere aggregation of criteria. A relation matrix can be formed using questions such as "*Does the feature e_i inflect the feature e_j?*" The reachability matrix can be calculated using Eqs. (8) and (9), as follows:

$$\mathrm{M} = \mathrm{D} + \mathrm{I} \tag{8}$$

$$\mathrm{M}^* = \mathrm{M}^k = \mathrm{M}^{k+1} \quad k > 1 \tag{9}$$

The reachability and the priority set are then calculated based on Eqs. (10) and (11), respectively, as presented below. Note that m_{ij} denotes the value of the i^{th} row and the j^{th} column.

$$A(t_i) = \{ t_j \mid m'_{ij} = 1\} \quad (10)$$
$$R(t_i) = \{ t_j \mid m'_{ij} = 1\} \quad (11)$$
$$R(t_i) \cap A(t_i) = R(t_i) \quad (12)$$

The levels and relations among the criteria can be determined and are applied in Eq. (12). In addition, the criterion's relations can be structurally and systematically expressed using the graph in which R represents the intersection of an antecedent set and a reachability set. The reachability matrix transforms each entry of the linguistic preferences into 1s and 0s.

3.4 Analytic Network Process

Saaty (1996) developed a new analysis method, ANP, which simultaneously takes into account both the relationships of feedback and dependence. ANP generalizes the pairwise comparison process, so that decision models can be built as complex dependence networks of decision objectives, criteria and alternatives that all influence among criteria and alternatives. The concept of the ANP is that influence does not necessarily have to flow only downwards, as is the case with the hierarchical structure. Influence can flow between any two criteria in the dependence network causing non-linear results of priorities of alternative choices (Tseng *et al*., 2008).

In addition, the consistency test is designed to ensure the consistency of judgments by decision makers throughout the decision making process. When inconsistencies exist in the pairwise comparison matrix A, Saaty (1980) proved that, for consistent reciprocal matrixes, the λ_{max} value is equal to the number of comparisons, or $\lambda_{max} = n$. Then Saaty gave a measure of consistency, called the consistency index (CI), as the deviation or degree of consistency, using the following formula:

$$CI = (\lambda_{max} - n) / (n - 1) \quad (13)$$

The consistency ratio (CR) is then defined as the ratio of CI to the mean random consistency index (RI), as follows:

$$CR = CI / RI \quad (14)$$

The CR is expected to be less than 0.1, which indicates that the consistency level of the pairwise comparison matrix is acceptable. When the CR is greater than 0.1, the results of the decision process are not consistent, suggesting that the decision maker needs to perform the pairwise comparison again. This study obtains the limited weighted supermatrix and allows for gradual convergence of the interdependent relationships to obtain the accurate relative weights among the criteria.

4. RESULTS

This section evaluates the implementation and performance for the case study firm, which utilized our approach for several reasons. First, the case study firm has to constantly improve its manufacturing processes while facing challenges as to how they could manage the GSCM in their competitive and changeable environments. Second, the case study firm must keep reforming in the industrial sector to cope with market competition and customer requirements. Expert opinions are obtained from an expert group that is composed of five professors and six senior management staff, who had extensive experience in consulting before this study.

4.1 Case Study Firm

The Taiwanese plants of COM Co., Ltd. were built for integrated circuit (IC) substrates and entered the IC packing field to meet customer demands for related products in 1998. The firm has been continuously developing new generation green technology, production process, enhancing its green competitiveness, fully satisfying the green market, and tighten up closer relationships with their suppliers and customers due to the quick replacement of electronic products and the rapid exploration of new green technologies, the research and development (R&D) is leading its competitors in meeting green product demands and exploring new green products in available markets. This firm is ranking 2nd largest printed circuit board manufacturer all over the world. This is called "focal firm" in the electronic supply chain.

In addition, the GSCM implementation and performance evaluation is relatively important to sustain when facing an ever-increasingly competitive and changeable environment. An expert group with eleven members strived to evaluate the proposed criteria in terms of the BSC concepts. Traditionally, the BSC approach is ignored the hierarchical relations among criteria or just simply follow the traditional framework with re-build the hierarchical framework. Hence, the expert group reviewed the criteria and proposed to rebuild the framework to construct the suitable hierarchical framework for the case firm. The expert group also intends to point out the most prioritized issues of the strategic management team. For better handling of this problem, the experts' management group should adopt possible solutions and develop GSCM criteria under the re-build BSC framework.

4.2 The Results

The objective of this empirical study is to demonstrate how ISM, fuzzy set theory, and ANP can be used to evaluate their performance and implementation. The expert group followed the four-step proposed procedures.

Step 1. Transform the qualitative and quantitative data into a comparable scale

The twenty criteria and four alternatives were measured in the TFNs, and a quantitative scale was used for the firm. The quantitative data must be transformed into a comparable scale using Eq. (1). The defuzzification process is employed in Eqs. (2)–(6). The TFNs were applied to transform the total weighted performance matrices into interval performance matrices, providing a_l and a_u. Using Eqs. (4) and (5), C_ε was transformed into crisp values that correspond to Epsilon values on comparable scales. Therefore, linguistic preferences were used to convert measures into TFNs (shown in Table 2), and the TFNs were converted into crisp values.

Table 3 presented the fuzzy synthetic evaluation of experts evaluated in terms of linguistic preferences. For aspects under AS1's pairwise comparison, the total weighted performance matrix was constructed using Eqs. (5) and (7) and applied to arrive at the a_l and a_u. For example, a_l = 0.5×(0.778–0.865)+0.865 = 0.767 and a_u = 0.865–0.5×(0.865–0.778) = 0.822. Last, the crisp value C_ε was computed using Eq. (7). The completed results were shown in Table 3.

Step 2. Building up a network framework

The experts decided to construct the inter-relations of the criteria within the firm's complex system and to interpret the inputs for pair-wise relations. They interpreted as the judgment of the group's decisions whether and how the criteria were related with Eqs. (8) and (9). An overall structure is extracted from the complex set of criteria and is transformed into a reachability matrix format by transforming the information in each entry of the linguistic preferences into 1s and 0s in the reachability matrix. The results of the study indicate that there are four levels in the hierarchical structure. The model is structural and information can be extracted based on the relations among the aspects and criteria. The matrix is partitioned by assessing the reachability and antecedent sets for each criterion, using Eqs. (10) and (11). The reachability set consists of the criterion itself and other criteria that it may help to achieve, shown in Table 4.

Meanwhile, the antecedent set is composed of the criterion itself and other criteria that may help achieve it.

Table 3. Example of fuzzy synthetic evaluation under C2

C2's pair comparison	(*l, m, u*)	a_l	a_u	C_ε
(A1, A2)	(0.756, 0.778, 0.865)	0.767	0.822	0.794
(A1, A3)	(0.535, 0.647, 0.785)	0.591	0.716	0.654
(A1, A4)	(0.658, 0.726, 0.856)	0.692	0.791	0.742
(A2, A3)	(0.655, 0.725, 0.812)	0.690	0.769	0.729
(A2, A4)	(0.529, 0.668, 0.752)	0.599	0.710	0.654
(A3, A4)	(0.432, 0.528, 0.665)	0.480	0.597	0.538

Table 4. Reachability matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
C1	1	1	1	1	1	0	1	0	1	1	1	0	1	0	1	1	1	1	1	1
C2	0	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1	0
C3	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
C4	1	1	0	1	0	0	1	0	1	1	1	0	1	1	1	1	1	1	1	1
C5	0	1	1	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0
C6	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	0
C7	0	1	0	1	0	0	1	1	1	1	1	0	0	1	1	0	0	0	0	0
C8	1	0	1	1	1	0	0	1	1	1	1	0	1	1	0	0	0	0	0	0
C9	0	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
C10	0	1	1	1	0	1	1	1	0	1	1	0	1	0	1	0	0	0	0	0
C11	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	0	1
C12	0	1	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1
C13	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0
C14	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1
C15	1	1	0	1	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0
C16	0	1	0	1	1	0	0	0	1	1	1	0	1	1	1	1	0	1	0	1
C17	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1
C18	1	1	1	1	1	0	0	0	1	0	1	0	1	1	1	0	0	0	0	1
C19	1	1	0	1	1	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1
C20	1	1	1	1	1	0	0	0	1	0	1	0	0	1	1	0	0	1	0	1

Using Eq. (12), the intersection of these sets is derived for all of the criteria. The criteria that have the same values in the reachability and intersection sets will be located at the top level of the ISM hierarchy. The top-level criteria in the hierarchy would not help to achieve any other criteria above the same level. Next, the top-level criteria are identified and removed from the list of the criteria. This process is repeated to find the criteria in the next levels.

The criteria C11 (top management support on green issues), C12 (the reduction of hazardous materials in the production process), C13 (green purchasing capabilities/design/production), C14 (life cycle assessment), and C15 (environmental management systems) are found at level III (internal operations aspects) and are presented in Table 6. Thereafter, C16 (innovation of green products measures), C17 (rate of new green product introduction per year), C18 (employee capabilities), C19 (internal green production plans), and C20 (conformance quality on green products) are placed at level IV (learning and growth aspect). Levels III and IV are called the customer aspect (AS3) and the financial aspect (AS4). The segregated results of the hierarchical structure have four levels, level I (C1, C2, C3, C4, and C5), level II (C6, C7, C8, C9, and C10), level III (C11, C12, C13, C14, and C15), and level IV (C16, C17, C18, C19, and C20), each with five criteria, as presented in Tables 5–7.

The matrix is partitioned by assessing the reachability and antecedent sets for each criterion. The reachability set consists of the criterion itself and other criteria that it may help to achieve, whereas the antecedent set consists of the criterion itself and other criteria that helped to achieve it. These identified levels help in building the digraph and the final model. The present case consists of the criteria along with their reachability set, antecedent set, intersection set and levels. The final hierarchical model is developed, as shown in Figure 2.

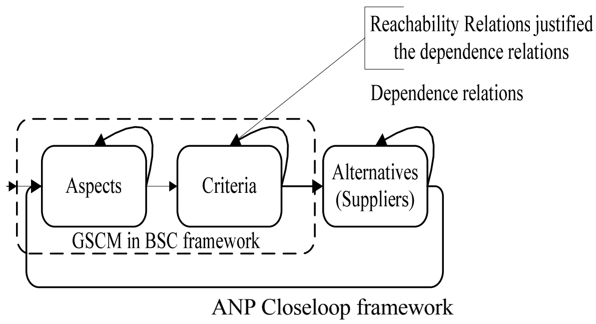

Figure 2. Analytical framework. GSCM: green supply chain management, BSC: balanced scorecard, ANP: analytical network process.

Table 5. Level I of firm's GSCM

Criteria	Reachability set: R(Ci)	Antecedent set: A(Ci)	Intersection	Level
C1	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	I
C2	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	I
C3	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	I
C4	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	I
C5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	I

GSCM: green supply chain management.

Table 6. Level III of firm's GSCM

Criteria	Reachability set: R(Ci)	Antecedent set: A(Ci)	Intersection	Level
C11	11, 12, 13, 14, 15	1, 2, 3, 4, 5, 11, 12, 13, 14, 15, 18, 19, 20	11, 12, 13, 14, 15	III
C12	11, 12, 13, 14, 15	3, 4, 5, 11, 12, 13, 14, 15, 14, 18, 19	11, 12, 13, 14, 15	III
C13	11, 12, 13, 14, 15	1, 4, 5, 7, 8, 11, 12, 13, 14, 15, 19, 20	11, 12, 13, 14, 15	III
C14	11, 12, 13, 14, 15	5, 10, 11, 12, 13, 14, 15, 18, 19	11, 12, 13, 14, 15	III
C15	11, 12, 13, 14, 15	3, 5, 11, 12, 13, 14, 15	11, 12, 13, 14, 15	III

GSCM: green supply chain management.

Table 7. Level IV of firm's GSCM

Criteria	Reachability set: R(Ci)	Antecedent set: A(Ci)	Intersection	Level
C16	16, 17, 18, 19, 20	3, 14, 15, 16, 17, 18, 19, 20	16, 17, 18, 19, 20	IV
C17	16, 17, 18, 19, 20	1, 5, 14, 16, 17, 18, 19, 20	16, 17, 18, 19, 20	IV
C18	16, 17, 18, 19, 20	1, 2, 3, 4, 5, 7, 8, 16, 17, 18, 19, 20	16, 17, 18, 19, 20	IV
C19	16, 17, 18, 19, 20	4, 5, 10, 16, 17, 18, 19, 20	16, 17, 18, 19, 20	IV
C20	16, 17, 18, 19, 20	1, 5, 16, 17, 18, 19, 20	16, 17, 18, 19, 20	IV

GSCM: green supply chain management.

Step 3. Calculating the relative weight for aspects and criteria

A series of pairwise comparisons are made on the importance weights in the aspects and criteria. The results of using Eq. (2) to justify the linguistic preferences and to apply the membership function are presented in Table 2. The defuzzification steps are recorded in Eqs. (3)–(7). Table 9 represents the decomposition of the matrix with weights for aspects under aspect 1 (AS1), presented as (0.298, 0.198, 0.273, 0.231). The value of λ_{max} is equal to 8.245. The consistency of the pairwise judgment of each comparison matrix is also checked by the consistency index and the consistency ratio; both should be less than 0.1. The matrix that is decomposed results in CI = 0.075 and CR = 0.064, using Eqs. (13) and (14). Again, these computational results are for the composition of the unweighted supermatrix, as shown in Table 8.

Step 4. Limiting the weighted supermatrix for the weight

The outcomes of the process in Table 10 form the unweighted supermatrix, which is for the interdependency among the aspects and criteria. Its columns contain the priorities that are derived from the pairwise comparisons resulting from Table 3. In an unweighted supermatrix, its columns may not be column stochastic. To obtain a stochastic matrix, i.e., each column sums to one, one can multiply the blocks of the unweighted supermatrix by the corresponding cluster priority. If the differences between the corresponding elements of a column are less than a very small number, then the process has converged for successive powers of the supermatrix. To derive the overall priorities of the elements, we need to multiply the supermatrix many times in turn until the columns stabilize and become identical in each block of submatrices. Our model involves dependences among the aspects and criteria and requires adjusting the unweighted supermatrix to make it column stochastic. Then the weighted supermatrix can be raised to limiting powers to calculate the priority weights. The supermatrix is made to converge to obtain a long-term stable set of weights, shown in Table 9.

The result indicates that the evaluation criteria seg-

Table 8. Unweighted supermatrix

	AS1	AS2	AS3	AS4	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	A1	A2	A3	A4
AS1	0.298	0.237	0.257	0.278	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.256	0.158	0.359	0.333
AS2	0.198	0.224	0.254	0.267	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.312	0.420	0.108	0.212
AS3	0.273	0.254	0.251	0.211	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.159	0.254	0.290	0.222
AS4	0.231	0.285	0.238	0.244	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.273	0.168	0.243	0.233
C1	0.102	0.046	0.068	0.035	0.175	0.055	0.056	0.085	0.051	0.000	0.259	0.000	0.095	0.105	0.072	0.000	0.068	0.000	0.085	0.085	0.068	0.099	0.106	0.088	0.047	0.052	0.048	0.068
C2	0.044	0.048	0.051	0.091	0.000	0.065	0.088	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.085	0.063	0.055	0.094	0.042	0.000	0.160	0.000	0.062	0.052	0.065	0.042
C3	0.052	0.062	0.046	0.042	0.000	0.000	0.092	0.000	0.000	0.000	0.000	0.184	0.000	0.000	0.000	0.000	0.000	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.046	0.042	0.068	0.021
C4	0.052	0.048	0.074	0.047	0.169	0.032	0.000	0.125	0.000	0.000	0.055	0.000	0.135	0.095	0.030	0.000	0.051	0.091	0.065	0.132	0.051	0.125	0.051	0.147	0.049	0.047	0.053	0.051
C5	0.046	0.052	0.063	0.042	0.000	0.034	0.068	0.000	0.109	0.000	0.000	0.000	0.136	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.065	0.032	0.049
C6	0.047	0.048	0.045	0.063	0.051	0.041	0.075	0.062	0.088	0.191	0.111	0.105	0.045	0.066	0.066	0.138	0.076	0.045	0.090	0.000	0.155	0.046	0.135	0.000	0.049	0.063	0.048	0.067
C7	0.051	0.055	0.058	0.058	0.000	0.097	0.000	0.067	0.000	0.000	0.069	0.053	0.053	0.052	0.052	0.000	0.000	0.057	0.056	0.000	0.000	0.000	0.000	0.000	0.056	0.058	0.055	0.055
C8	0.046	0.047	0.041	0.051	0.038	0.000	0.042	0.085	0.138	0.000	0.000	0.043	0.042	0.056	0.095	0.000	0.068	0.065	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.051	0.038	0.068
C9	0.044	0.045	0.042	0.046	0.000	0.053	0.000	0.072	0.100	0.158	0.000	0.047	0.095	0.049	0.049	0.150	0.043	0.000	0.085	0.294	0.085	0.095	0.044	0.092	0.049	0.062	0.052	0.043
C10	0.051	0.048	0.050	0.051	0.000	0.086	0.075	0.087	0.086	0.037	0.096	0.050	0.000	0.084	0.095	0.000	0.055	0.074	0.046	0.000	0.000	0.000	0.000	0.000	0.045	0.031	0.075	0.055
C11	0.045	0.063	0.042	0.045	0.081	0.095	0.095	0.035	0.085	0.096	0.072	0.215	0.000	0.000	0.038	0.000	0.000	0.045	0.063	0.047	0.083	0.134	0.000	0.122	0.042	0.045	0.047	0.044
C12	0.044	0.052	0.052	0.052	0.000	0.032	0.088	0.041	0.000	0.135	0.000	0.052	0.060	0.068	0.068	0.109	0.053	0.051	0.056	0.138	0.053	0.000	0.122	0.137	0.040	0.052	0.048	0.053
C13	0.049	0.044	0.051	0.056	0.042	0.083	0.000	0.000	0.000	0.124	0.124	0.157	0.051	0.050	0.070	0.108	0.051	0.085	0.000	0.054	0.095	0.000	0.000	0.000	0.047	0.056	0.051	0.051
C14	0.041	0.040	0.036	0.045	0.000	0.038	0.136	0.000	0.000	0.259	0.214	0.095	0.043	0.169	0.041	0.215	0.052	0.085	0.039	0.000	0.166	0.258	0.000	0.052	0.039	0.067	0.035	0.067
C15	0.039	0.038	0.056	0.029	0.052	0.024	0.000	0.048	0.000	0.000	0.000	0.000	0.052	0.000	0.067	0.095	0.109	0.041	0.038	0.000	0.000	0.000	0.000	0.000	0.052	0.029	0.047	0.054
C16	0.048	0.044	0.044	0.059	0.000	0.095	0.000	0.059	0.125	0.000	0.000	0.000	0.044	0.064	0.046	0.000	0.085	0.048	0.045	0.156	0.000	0.146	0.000	0.058	0.085	0.059	0.063	0.042
C17	0.052	0.094	0.051	0.047	0.105	0.076	0.000	0.050	0.059	0.000	0.000	0.000	0.049	0.067	0.067	0.185	0.055	0.050	0.051	0.000	0.105	0.000	0.250	0.076	0.058	0.059	0.049	0.042
C18	0.043	0.052	0.047	0.046	0.095	0.032	0.100	0.090	0.067	0.000	0.000	0.000	0.049	0.000	0.063	0.000	0.087	0.039	0.099	0.000	0.000	0.000	0.000	0.056	0.048	0.046	0.065	0.025
C19	0.050	0.046	0.044	0.051	0.086	0.024	0.000	0.055	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.062	0.068	0.075	0.000	0.097	0.051	0.132	0.089	0.043	0.049	0.025	0.058
C20	0.054	0.029	0.040	0.044	0.106	0.038	0.085	0.039	0.044	0.000	0.000	0.000	0.052	0.000	0.047	0.000	0.000	0.047	0.052	0.000	0.000	0.046	0.000	0.083	0.059	0.015	0.036	0.045
A1	0.241	0.326	0.268	0.152	0.355	0.278	0.258	0.175	0.119	0.251	0.358	0.355	0.258	0.248	0.355	0.335	0.249	0.352	0.259	0.158	0.505	0.150	0.162	0.249	0.351	0.153	0.354	0.250
A2	0.550	0.125	0.214	0.208	0.138	0.119	0.256	0.158	0.349	0.178	0.281	0.145	0.217	0.357	0.146	0.235	0.421	0.157	0.364	0.459	0.152	0.247	0.352	0.158	0.118	0.383	0.202	0.246
A3	0.052	0.224	0.253	0.356	0.125	0.243	0.211	0.333	0.167	0.252	0.215	0.214	0.185	0.175	0.247	0.189	0.139	0.108	0.175	0.137	0.163	0.243	0.211	0.333	0.167	0.252	0.215	0.255
A4	0.157	0.325	0.265	0.284	0.382	0.360	0.275	0.334	0.365	0.319	0.146	0.286	0.340	0.220	0.252	0.241	0.191	0.383	0.202	0.246	0.180	0.360	0.275	0.260	0.364	0.212	0.229	0.249

Table 9. Converged supermatrix

	AS1	AS2	AS3	AS4	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	A1	A2	A3	A4	Rank
AS1	0.055	0.055	0.055	0.055	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.055	0.055	0.055	0.055	1
AS2	0.051	0.052	0.052	0.052	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.052	0.051	0.052	0.052	2
AS3	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.046	0.047	0.047	0.046	0.046	0.047	0.047	0.047	0.047	0.046	0.047	0.046	0.047	0.047	0.047	0.047	0.047	4
AS4	0.048	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	3
C1	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.026	0.027	0.026	0.027	0.027	0.027	0.026	0.027	0.027	0.027	0.027	0.026	0.027	0.026	0.027	0.027	0.027	0.027	0.027	2
C2	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	11
C3	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	20
C4	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.024	0.025	0.025	0.025	0.025	0.025	4
C5	0.014	0.014	0.014	0.014	0.013	0.014	0.014	0.014	0.014	0.014	0.013	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	18
C6	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	3
C7	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	13
C8	0.017	0.017	0.017	0.017	0.016	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.016	0.017	0.017	0.017	0.017	0.017	14
C9	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	5
C10	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.019	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	12
C11	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	9
C12	0.022	0.022	0.022	0.022	0.023	0.022	0.023	0.022	0.022	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.022	0.023	0.022	0.023	0.023	0.022	0.022	0.022	0.022	7
C13	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	8
C14	0.028	0.028	0.028	0.028	0.029	0.028	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.028	0.029	0.029	0.029	0.029	0.028	0.028	0.028	0.028	1
C15	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	17
C16	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	10
C17	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	6
C18	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	15
C19	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	16
C20	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	19
A1	0.109	0.109	0.109	0.109	0.110	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.110	0.109	0.110	0.109	0.109	0.109	0.109	0.109	2
A2	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.098	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	3
A3	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	4
A4	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	1

regate into the four hierarchical levels, that the weight of an aspect's sequence is AS1, AS2, AS3, and AS4 and that the criteria ranking is C14, C1, C6, C4, C9, C17, C12, C13, C11, C16, C2, C10, C7, C8, C18, C19, C15, C5, C20, and C3. The suppliers are ranked as A4, A1, A2, and A3. Valuable cues are obtained for making profound decisions and implementation plans. To assess the effectiveness of the proposed solution, this paper conducted a post-survey discussion with the expert and professional group. The discussion results are summarized as follows.

First, it is a common understanding that GSCMs often emphasize the expectation of improving environmental performance. However, the resulting LCA (C14) contains the importance criteria that are considered in the implementation plan rather than in other plans. The most highly weighted aspect is the financial aspect (AS1). This high weight is because the life cycle assessment has the goal of maintaining the firm's competitiveness in the long run, and financial support is a subject that they are always aware of in their organization.

Specifically, the financial aspect suggest that annual growth in green products (C1) and growth from new green products per year (C4) are the most generally agreed criteria of GSCM performance evaluation. There are practical implications of the study's findings for financial performance-driven organizations. Now, it appears that the case firm has adopted a relatively financial performance-driven that can be used in its GSCM implementation context for the benefit of both firms and environmental management, i.e., internal control process and external supplier decision. Thus, the implementation of these criteria for measuring GSCM performance indicates the prioritization of criteria implementation in particular, and the firm in general, might exploit to enhance their operations and, in turn, improve life cycle assessment (C14), and customer retention (C6).

In addition, LCA is a technical tool to assess a product's environmental impacts associated with all of the stages of a product's life, from cradle-to-grave, for example, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance and disposal or recycling. This strategy helps to keep an outlook on environmental awareness when compiling an inventory of relevant energy and material inputs and evaluates the potential impacts associated with identified product life stages to interpret the results.

The proposed twenty criteria allow managers and researchers to better understand the differences in environmental operations, activities and specific green management interventions. The BSC structure allows a firm to control and evaluate management practices and can describe the firm's supplier selection dilemmas. For example, in Step 2, a set of TFNs (linguistic preferences) represents the overall importance of the evaluator's perception on aspects and criteria of the four alternatives. Here, the top five criteria were as follows: Life cycle assessment (C14); Annual growth in green products (C1); Customer retention/percentage of growth with existing customers (C6); Growth from new green products per year (C4); and Customer/supplier profitability on green products (C9). The result also indicates the BSC aspect weights as follows: Financial aspect (AS1); Customer aspect (AS2); Learning and growth aspect (AS4); and Internal operations aspect (AS3).

In view of the weights, the LCA assesses the environmental impacts and resource consumptions associated with the existence of products throughout their distribution and use to disposal and recycling. The process life cycle orientation includes the extraction of raw materials, manufacture, packaging, storage, distribution, use and recycling-destruction, which is the entire process of green products from cradle to grave, including the extraction of resources for production. This approach is to evaluate the whole impact of a green product without geographic and temporal limits and allows achieving a product's maximum performance with a firm's GSCM implementation and performance. The traditional approach can be evaluated by life cycle costing. In addition, life cycle assessment and life-cycle costing can be applied as separate management tools. For example, the avoidance of unnecessary operational processes or maximized functionality leads to cost and environmental impact minimization. Ultimately, environmental and economic perspectives should be considered simultaneously, and avoiding duplications and cost considerations should be complemented by a firm's GSCM plan.

In a broader sense, the proposed hybrid method in the approach to GSCM associated with the BSC concept can also be used as an analytical monitoring tool to further develop or construct an overall supplier evaluation. It is favorable to use ANP to handle the problem of dependence relations, especially the relations that are identified from the initial reachability matrix. This study integrated the ISM, fuzzy set theory and ANP together to provide more valuable information for decision-making (Wu *et al.*, 2009; Tseng, 2009). For the practice of management, BSC is sufficient for organizational managers to better understand the relevant aspects and criteria. Moreover, the managers can capture a fairly complete picture of a firm's GSCM while assessing the relative performance of the components that were developed, validated, and operationalized by this approach.

5. CONCLUSIONS

This study suggests the twenty criteria that are critical attributes to the four BSC aspects of GSCM implementation and performance measures. The manufacturers that wish to improve their performance must constantly monitor their implementation. The criteria are measured in linguistic preferences and can be used as a self-diagnostic tool to identify areas where specific improvements are needed and pinpoint the aspects of the manufacturer's system. Hence, this study focused on the development of hierarchical structures using ISM and expresses the uncertainty of the model with fuzzy set theory to handle dependence relations among criteria applied with ANP. The proposed method reflects these dependences, allows for uncertainties and produces results that are highly reliable. Ultimately, to achieve optimal results, the BSC aspects and criteria must be considered and evaluated simultaneously. Managers might consider the GSCM implementation for each individual aspect and criterion and may identify the areas in need of specific attention. For example, if a manufacturer underperforms in the "life cycle assessment" and "annual growth in green products", this underperformance would imply a need for improvement actions or for information on that specific criterion. Nevertheless, this study confirmed that the dependence relations that occurred and adoption of the BSC framework for their performance enhance the GSCM practices. We recommend that both practitioners and theorists note this systemic set of dependence relations and the use of linguistic preferences to model a hierarchical structure and be mindful that environmental practices are neither incremental nor compartmental.

Hence, this study proposed a technique for selecting alternatives in the presence of uncertainty. However, the evaluator's judgment is often uncertain and, in a hierarchical structure, cannot always be evaluated in prior studies. An empirical example of supplier selection uses a proposed hybrid approach and illustrates the application of the proposed BSC aspects and criteria in a GSCM practicing firm. The experimental results indicated that the proposed approach is reliable and reasonable, and an optimal alternative was selected from the four possible alternatives. The proposed model can easily and effectively accommodate the validated criteria. The model establishes a foundation for future study and is appropriate for predicting uncertain criteria. To improve a firm's performance and to provide information that will have the greatest effect on reducing uncertainty, a firm may apply this model to evaluate and determine the optimal supplier.

This framework shows that more generic, situational characters, such as the number of suppliers available, the historic measures, the importance of environmental friendly concerns and the whole supplier selection criteria are more determinative for the suitability of a proposed method. This study also includes some limitations that require further research. This study was designed to evaluate the case of a firm's GSCM implementation and supplier selection problem. This study has contributed to the literature in the following specific ways: 1) proposing a research BSC concept that integrates the criteria under uncertainty, 2) developing valid and reliable measures for the pair comparison based on an expert's perceptions and quantitative data from a case firm, and 3) modeling a hierarchical structure to evaluate the optimal supplier using ISM and fuzzy set theory and ANP for analysis. In a practical firm's GSCM problems, there are vast numbers of criteria that are typically dependent and have elusive qualitative information. This study developed an effective hybrid method to select the most appropriate supplier in terms of GSCM. The proposed evaluation framework has been validated with its effectiveness and simplicity in selecting the supplier in GSCM for the case firm. Different groups of firms may have different decision-making processes, such as different scales and industrial sectors. It might be meaningful to test the proposed model by considering the effects of more firms' characteristics for future studies. The measures were somewhat myopic. It would be better to recommend additional measures to be included in a longitudinal study. It would also be an interesting extension to examine incomplete information in the BSC performance measures in future studies.

REFERENCES

Agarwal, A., Shankar, R., and Tiwari, M. K. (2007), Modeling agility of supply chain, *Industrial Marketing Management*, **36**(4), 443-457.

Al-Najjar, B. and Alsyouf, I. (2003), Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making, *International Journal of Production Economics*, **84**(1), 85-100.

Banker, R. D. and Datar, S. M. (1989), Sensitivity, precision, and linear aggregation of signals for performance evaluation, *Journal of Accounting Research*, **27**(1), 21-39.

Bremser, W. G. and Barsky, N. P. (2004), Utilizing the balanced scorecard for R&D performance measurement, *R&D Management*, **34**(3), 229-238.

Cebeci, U. (2009), Fuzzy AHP-based decision support system for selecting ERP systems in textile industry by using balanced scorecard, *Expert Systems with Applications*, **36**(5), 8900-8909.

Chen, F. H., Hsu, T. S., and Tzeng, G. H. (2011), A balanced scorecard approach to establish a performance evaluation and relationship model for hot spring hotels based on a hybrid MCDM model combining DEMATEL and ANP, *International Journal of Hospitality Management*, **30**(4), 908-932.

Diabata, A. and Govindan, K. (2011), An analysis of the drivers affecting the implementation of green supply chain management, *Resources, Conservation and Recycling*, **55**(6), 659-667.

Dreyer, B. and Gronhaug, K. (2004), Uncertainty, flexibility, and sustained competitive advantage, *Journal of Business Research*, **57**(5), 484-494.

Dyson, R. G. (2000), Strategy, performance and operational research, *Journal of the Operational Research Society*, **51**(1), 5-11.

Fu, C. and Yang, S. (2012), The combination of dependence-based interval-valued evidential reasoning approach with balanced scorecard for performance assessment, *Expert Systems with Applications*, **39** (3), 3717-3730.

Green, K., Morton, B., and New, S. (1996), Purchasing and environmental management: interaction, policies and opportunities, *Business Strategy and the Environment*, **5**(1), 188-197.

Harland, C. M., Lamming, R. C., and Cousins, P. D. (1999), Developing the concept of supply strategy, *International Journal of Operations and Production Management*, **19**(7), 650-674.

Johnston, D. A., McCutcheon, D. M., Stuart, F. I., and Kerwood, H. (2004), Effects of supplier trust on performance of cooperative supplier relationships, *Journal of Operations Management*, **22**(1), 23-38.

Kaplan R. S. and Norton D. P. (1992), The balanced scorecard-measures that drive performance, *Harvard Business Review*, **70**, 71-79.

Klassen, R. D. and Whybark, D. C. (1999), Environmental management in operations: the selection of environmental technologies, *Decision Sciences*, **30**(3), 601-631.

Li, S., Ragu-Nathan, B., Ragu-Nathan, T. S., and Subba Rao, S. (2006), The impact of supply chain management practices on competitive advantage and organizational performance, *Omega*, **34**(2), 107-124.

Lin, Y. H., Tseng, M. L., Cheng, Y. L., Chiu, A. S. F., and Geng, Y. (2013), Performance evaluation of technological innovation capabilities in uncertainty, *Scientific Research and Essays*, **8**(13), 501-514.

Lin, Y., Cheng, H. P., Tseng, M. L., and Tsai, J. C. C. (2010), Using QFD and ANP to analyze the environmental production requirements in linguistic preferences, *Expert Systems with Applications*, **37** (3), 2186-2196.

Linton, J. D., Klassen, R., and Jayaraman, V. (2007), Susainable supply chains: an introduction, *Journal of Operations Management*, **25**(6), 1075-1082.

Pagell, M., Yang, C. L., Krumwiede, D. W., and Sheu, C. (2004), Does the competitive environment influence the efficacy of investments in environmental management? *Journal of Supply Chain Management*, **40**(3), 30-39.

Pan, N. F. (2008), Fuzzy AHP approach for selecting the suitable bridge construction method, *Automation in Construction*, **17**(8), 958-965.

Pineno, C. J. (2001), The balanced scorecard: an incremental approach model to health care management, *Journal of Health Care Finance*, **28**(4), 69-80.

Saaty, T. L. (1980), *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*, McGraw-Hill, New York, NY.

Saaty, T. L. (1996), *Decision Making with Dependence and Feedback: The Analytic Network Process: The Organization and Prioritization of Complexity*, RWS Publications, Pittsburgh, PA.

Sarkis, J. (1998), Evaluating environmentally conscious business practices, *European Journal of Operational Research*, **107**(1), 159-174.

Singh, M. D., Shankar, R., Narain, R., and Agarwal, A. (2003), An interpretive structural modeling of knowledge management in engineering industries, *Journal of Advances in Management Research*, **1**(1), 28-40.

Stanley, L. L. and Wisner, J. D. (2001), Service quality along the supply chain: implications for purchasing, *Journal of Operations Management*, **19**(3), 287-306.

Tseng, M. L. (2009), Application of ANP and DEMATEL to evaluate the decision-making of municipal solid waste management in Metro Manila, *Environmental Monitoring and Assessment*, **156**(1-4), 181-197.

Tseng, M. L. (2010), Implementation and performance evaluation using the fuzzy network balanced scorecard, *Computers and Education*, **55**(1), 188-201.

Tseng, M. L. (2011), Green supply chain management with linguistic preferences and incomplete information, *Applied Soft Computing*, **11**(8), 4894-4903.

Tseng, M. L. (2013), Modeling sustainable production indicators with linguistic preferences, *Journal of Cleaner Production*, **40**, 46-56.

Tseng, M. L. and Lin, Y. H. (2009), Application of Fuzzy DEMATEL to develop a cause and effect model of municipal solid waste management in Metro Manila, *Environmental Monitoring and Assessment*, **158**(1-4), 519-533.

Tseng, M. L., Chiang, J. H., and Lan, L. W. (2009), Selection of optimal supplier in supply chain management strategy with analytic network process and choquet integral, *Computers and Industrial Engineering*, **57**(1), 330-340.

Tseng, M. L., Lin, Y. H., Chiu, A. S. F., and Liao, J. C. H. (2008), Using FANP approach on selection of competitive priorities based on cleaner production implementation: a case study in PCB manufacturer, Taiwan, *Clean Technologies and Environmental Policy*, **10**(1), 17-29.

Wang, C. H., Lu, I. Y., and Chen, C. B. (2010), Integrating hierarchical balanced scorecard with non-additive fuzzy integral for evaluating high technology firm performance, *International Journal of Production Economics*, **128**(1), 413-426.

Warfield, J. N. (1974), Developing interconnected matrices in structural modeling, *IEEE Transactions on Systems Man and Cybernetics*, **4**(1), 81-87.

Wu, H. Y., Tzeng, G. H., and Chen, Y. H. (2009), A fuzzy MCDM approach for evaluating banking performance based on Balanced Scorecard, *Expert Systems with Applications*, **36**(6), 10135-10147.

Wu, S. I. and Hung, J. M. (2008), A performance evaluation model of CRM on non-profit organizations, *Total Quality Management*, **19**(4), 321-342.

Yao, Y., Palmer, J., and Dresner, M. (2007), An interorganizational perspective on the use of electronically-enabled supply chains, *Decision Support Systems*, **43**(3), 884-896.

Zadeh, L. A. (1975), The concept of a linguistic variable and its application to approximate reasoning-III, *Information Sciences*, **9**(1), 43-80.

Zadeh, L. A., (1965), Fuzzy set, *Information and Control*, **18**(3), 338-353.

Zhu, Q. and Geng, Y., (2001), Integrating environmental issues into supplier selection and management: a study of large and medium-sized state-owned enterprises in China, *Greener Management International*, **35**, 27-40.

Zhu, Q. and Sarkis, J. (2004), Quality management and environmental management practices: an analysis of different size organizations in China, *Journal of Environmental Quality Management*, **13**(3), 53-64

Zhu, Q., Sarkis, J., and Lai, K. H. (2008), Confirmation of a measurement model for green supply chain management practices implementation, *International Journal of Production Economics*, **111**(2), 261-273.

Zsidisin, G. A. and Siferd, S. P. (2001), Environmental purchasing: a framework for theory development, *European Journal of Purchasing and Supply Management*, **7**(1), 61-73.