Evaluating the green supply chain management using life cycle assessment approach in uncertainty

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Abstract: - Green supply chain management in product life cycle assessment is a complex uncertainty concept that is difficult to determine based on a firm's real situation because measuring GSCM requires a set of qualitative measures. A set of criteria is proposed and uses a hybrid fuzzy multi-criteria decision-making (MCDM) technique to address the dependence relations of criteria in hierarchical structure with the aid of the interpretive structural modeling (ISM) and analytical network process (ANP) in linguistic preferences. Fuzzy set theory is used to interpret the linguistic preference in accordance with the subjective evaluation. The evaluation results obtained through the proposed approach are for two reasons. First, the results are generated by a group of experts in the presence of motile criteria, and second, the linguistic preference approach reduces the distortion and loss of information. Managers judge the need to improve and determine which criteria provide the most effective direction towards improvement. The results and implications are discussed.

Key-words: - green supply chain management; product life cycle assessment; interpretive structural modeling; fuzzy set theory; Analytical network process

1 Introduction

The electronic industry has experienced increasing environment consciousness and to achieve the waste elimination reduced the impact to the environment due to the European Union has established a range of environmental policies such as RoHS (Restriction of Hazardous Substances) and WEEE (waste electronics and electrical equipment. These closely linked directives ban the use of six hazardous chemicals in the manufacture of electrical and electronic equipment and set collection, recycling and recovery targets for eliminated waste, respectively. Essentially, RoHS is applied to the design of products whereas WEEE is aimed at the product life cycle assessment (PLCA). Green supply chain management (GSCM) has emerged as an approach to balance these competitive requirements. It forces the organizations to consider the PLCA design in order to fulfill the requirement of WEEE directive. Within GSCM in PLCA practices, recoverable product environments, and the design of these products and materials, have become an increasingly important segment of the overall push in electronic industry towards environmentally conscious manufacturing bases. The most of Taiwanese printed circuit board (PCB) firms are original equipment manufacturing (OEM), and they are expected to practices and exercise on the GSCM in order to develop a competitive advantage in the green marketplace. Here, the role of environmentally based practices to design into the GSCM in PLCA design〔19〕〔32〕〔40〕〔42〕〔44〕〔39〕.

The management has to balance efforts to reduce costs and innovate while maintaining good environmental performance〔27〕. Even though PLCA has significant environmental motivations, regulatory, competitive and economic pressures also play roles in its adoption across electronic sectors. GSCM and PLCA analysis have become an important competitive approach for organizations in this dramatic environment. However, while studies investigating environmental management exist for specific stand-alone industries, this study contributes to the body of knowledge by further investigating GSCM in a developing economy and the determination of industry differences in embracing the practices〔47〕. However, the limited understanding of GSCM in PLCA design has hampered the development of a widely accepted framework that would characterize and categorize firm's green activities. Nevertheless, various studies can be found in the literatures〔55〕〔57〕〔58〕〔35〕〔41〕. Hence, this study proposed to merge the PLCA design into GSCM practices.

In literatures, there are fewer studies of the development the study in measuring GSCM of firm's activities in hybrid multi-criteria decision making (MCDM) technique in uncertainty. Several studies also suggested the implementation of GSCM as an effective method to improve business sustainability〔31〕; it is overhauling operation process is to achieve the firm's goal of waste elimination and reduce the impact to the environment according to the PLCA design. It is important for the firm's continuous improvement in the environment with great emphasis on green product development in a competitive and sustainable market. There is a growing consensus trend that sustainability is necessary to move towards developing GSCM for promoting and measuring achievements. However, practicing GSCM requires identification of appropriate measures in order to complete robust study and to advance the body of knowledge in a field, both academically and practically. Academically, greater attention needs to be focused on employing multi-criteria, assessing the criteria for content validity and purifying them through extensive literature reviews to effectively and empirically advance theory within this field〔25〕〔57〕〔58〕

〔35〕〔44〕〔23〕. Practically, firms can benefit from the development of reliable and valid criteria to practices through implementation. The practitioner applies these criteria for benchmarking and continuous improvement when seeking to harmonize environment and SCM practices. The major cause for the continued deterioration of the global environment is the unsustainable pattern of consumption and production, especially in industrialized nations such as Taiwan.

For the purpose, to aid GSCM evaluation, this study finds practical application of the hybrid MCDM technique in considering expert opinions. The MCDM in real world systems very often deals with subjective human preferences. People express thoughts and perceptions using natural language which is often vague or difficult to state mathematically. Although the meaning of a word might be well defined, determining the boundaries with which objects do or do not belong to becomes uncertain when using the word as a label for a set 〔42〕. However, a set of criteria has the nature of hierarchical and dependence relations. The interpretive structural modeling (ISM) is to evaluate the subjective judgment and interactive relations among the criteria into a hierarchical structure〔1〕 and applies fuzzy set theory to appropriately express human's judgment in proposed criteria, the interactive relations present the interdependence among criteria. Moreover, the traditional statistical approach is not well-suited for evaluating these dependence relations, whereas the analytical network process (ANP) is known to be well-suited to handling a hierarchal structure with dependence relations. ANP is helpful in assigning weights on these measures in a closed-loop hierarchical structure 〔40〕〔41〕〔38〕. This study summarizes the principles of the theories and its modeling schemes in diagnosis, and reviews its practical applications combined with linguistic preferences. In this case study, a novel hybrid fuzzy MCDM approach is developed to determine and integrate GSCM criteria in choosing optimal alternative.

The challenges of this field focus on the building hierarchical structure, subjectivity of the measures and evaluate on dependence relations in rapidly changing environmental information. Considering the goal of the case firm to maintain competitiveness while at the same time complying with environmental regulations, this study aims to capture linguistic preferences in the selection of an alternative supplier using a proposed model. This study contributes to its attempt to integrate a number of criteria from various literatures in supply chain and environmental management and another contribution is to guide firms in understanding the different criteria in their practices. The results are also useful for developed country organizations that have invested or plan to invest in Taiwan. This study starts with a brief introduction and will begin with a literature review in Section 2, introducing the GSCM and PLCA as well as defining the study criteria. It is followed by additional research background of GSCM. Moreover, section 3 will explain our selection of industries grounding of this investigation that helps to further develop insights into electronic industry. Section 4 describes the study design and measures developed for this study, the data analysis and results are presented. Section 5 discusses the managerial implications of GSCM in Taiwan. Section 6 concludes this study by providing areas for future study.

2 Literature Review

The GSCM criteria have been used to explain the green planning, materials control and external information flows. Researchers categorize it into strategic, inter-organization, internal service quality, addressing the challenge of selecting green suppliers and purchasing perspective in order to improve firm's competitiveness. GSCM can be defined as the direct involvement of firms with its suppliers and customers in planning jointly for solutions to reduce the environmental impact from production processes and products, for environmental management and exchange of technical information with a mutual willingness to learn about each other's operations plan, and for setting goals for environmental improvement. These activities imply strengthening cooperation among those involved to reduce the environmental impact associated with material flows in the GSCM in PLCA.

2.1 GSCM and LCA

Existing literature has provided an abundant range of definitions for GSCM regarding various aspects. For instance, Green *et al*. 〔14〕 suggest that green supply means innovation in the supply chain management and industrial purchasing is deeply taken into account in the context of environmental benefits should be included reduction, recycling, reuse and the substitution of materials. Moreover, Van Hock and Erasmus 〔48〕 claimed that green practices has emerged as an essential and effective approach for organizations to gain profit and market share objectives based on environmental risk elimination and eco-efficiency enhancement. Hence, GSCM philosophy focuses on how firms utilize their suppliers' processes, technology and capability, and integrating environmental concerns to enhance its competitive advantage. It is not only focused on products and production processes but also includes materials sourcing. Because GSCM focuses on the immediate outcome of the supplier on green efforts, and on the means by which more green operations or products might be achieved, buyer requirements are often incorporated in the conceptualization of green supply chain. This collaboration can take place simultaneously upstream with the green suppliers 〔3〕〔57〕. Vachon and Klassen 〔46〕 asserts that environmental collaboration was defined specifically to focus on inter-organizational interactions between supply chain members including aspects such as joint environmental goal-setting, shared environmental planning, and working together to reduce pollution or other environmental impacts.

In addition, a well-integrated GSCM involves coordinating the flow of materials and information between suppliers, manufacturers and customers, and implementing product postponement and mass customization in the supply chain, for assessing the environmental impacts and resource consumption associated with the existence of products throughout their entire life-cycle from cradle to grave, from the extraction of resources over production, distribution and use to disposal and recycling, called product life cycle assessment 〔52〕〔2〕. Zhu and Sarkis 〔56〕 presented environmental directives issued by the European community may have led Chinese firms to have higher environmental awareness and stronger drive for GSCM practice. The pressure to establish long-term relationship with foreign firms in China and export more products may also have driven Chinese firms to better implement GSCM.

Zhu *et al*. [58] empirically investigate the construct of and the scale for evaluating GSCM practices among 341 Chinese manufacturers, there are two measurement models were tested and compared by confirmatory factor analysis, and the empirical findings suggested that the two models are reliable and valid. Shang *et al.* [33] identified six dimensions were: green manufacturing and packaging, environmental participation, green marketing, green suppliers, green stock and green eco-design, and indicated that based on the resource-based view, the capability of the green marketing oriented group was considered to be the deployment of a collection of resources that enables it to successfully compete against rivals. The green product design has been transferred to all stakeholders due to its interdependence relations to all stakeholders; the LCA needs to be included in the GSCM practices [17] .

For GSCM in PLCA practices, firms need to have extensive supplier selection and performance evaluation processes since the supplier plays an important role in practices [21] . Suppliers normally have long-term contracts with the users and provide their services for multiple functions or develop close service with customers. In the past decade, many studies discussed the green supplier selection model and a number of literatures focused on supplier involvement and performance [9] [49] [36] [24] [44] . Chou and Chang [10] proposed a system evaluating alternative suppliers that utilizes SCM strategy to identify supplier qualified criteria and the resulting model allows decision-maker to incorporate the supply risks of individual suppliers into final decision making. Chan and Kumar [5] identified some of the important and critical criteria including risk factors for the development of an efficient system for global supplier selection. Wang and Che [50] presented a model using fuzzy performance indicators, and showed the integration of different criteria that allows the supplier selection of a specific commercial product to be explored and modeled. Li *et al.* [24] presented another way of supplier selection using grey based approach, but the computation process seem to be insufficient, showing unreasonable approach for the fuzzy number. Tseng *et al.* [44] studied the selection of appropriate suppliers using analytical network process and choquet integral given a specific SCM strategy considering a set of requirements and evaluation criteria. . This can help manufacturing firms build up its competitive advantages from the valuable cues in this intensive review. Therefore, this study rises up the topic of GSCM criteria evaluation and deal with supplier assessment, in order to compose a hierarchical GSCM structure with subjective human preferences and dependence relations.

2.2 Proposed MCDM method

There are different studies approaches to supplier selection problems. Chen *et al.* [7] used TOPSIS to rank suitable suppliers based on quantitative and qualitative factors they identified such as quality, price, and flexibility and delivery performance. Recent studies in multi-criteria supplier selection problems such as Humphreys *et al.* [18] proposed a hierarchical fuzzy system with scalable fuzzy membership functions to facilitate incorporation of environmental criteria in the selection process. Tseng *et al.* [44] constructed a MCDM process for GSCM to help managers in measuring and evaluating performance of suppliers using fuzzy analytical hierarchy process (AHP). Tseng *et al.* [43] developed an integrated approach of AHP improved by rough sets theory and multi-objective mixed integer programming to simultaneously determine the number of suppliers to employ and the order quantity allocated to these suppliers in the case of multiple sourcing and multiple products with multiple criteria and supplier capacity constraints. Wang and Che [50] presented a model using fuzzy performance indicators, and showed the integration of different criteria that allows the supplier selection of a specific commercial product to be explored and modeled.

In addition, Li *et al.* [24] presented another way of supplier selection using grey based approach, but the computation process seem to be insufficient, showing unreasonable approach for the fuzzy number. Given the recent studies, literature still lacks work in considering the optimal supplier selection in light of both environmental aspect and SCM criteria. With environmental awareness, much focus has been solely on incorporating such considerations. Tseng *et al.* [44] proposed the SCM strategy in the supplier selection problem with uncertainty. All conventional SCM criteria need to be incorporated together with environmental criteria to find the most suitable supplier in a comprehensive model. Sanayei *et al.* [30] proposed linguistic values are used to assess the ratings and weights for these factors. These linguistic ratings can be expressed in trapezoidal or triangular fuzzy numbers. Then, a hierarchy MCDM model based on fuzzy sets theory and VIKOR method is proposed to deal with the supplier selection problems in the supply chain system. Tseng [38] presented the suitable supplier is a key strategic direction in eliminating environmental impact. The firm's GSCM criteria and supplier selection need to be unified as a system to improve the firm's performance and identified the appropriate strategic direction applied proposed criteria using the fuzzy set theory and ANP together.

In concludes, this study proposes a hybrid MCDM technique based to deal with a perception approach in GSCM evaluation. There are very few studies applied this hybrid technique in solving particular management solution. The ISM builds the hierarchical structure, fuzzy set theory accounts for the vagueness of the language used to express the qualitative criteria whereas ANP deals with the dependence relations.

2.3 Proposed GSCM criteria

The outcome of literature review together with inputs from industry and academia compose the proposed criteria in this study which are the GSCM requirements for an optimal supplier. Comprehensive discussion and literature reviews resulted to a total of 18 criteria.

To ensure that the profitability of the supplier (C2) is an important part of the firm's practices, GSCM has become critical in establishing value-added content 〔22〕〔20〕〔53〕. Moreover, the reliability of delivery (C1), defined as the ability to meet delivery schedules or promises, and the ability to react quickly to customer orders, is critical to improving the firm's customer service. The product conformance quality (C5), defined as the ability of the firm to satisfy the customer needs, is critical to the firm's success 〔6〕. Tan *et al.* 〔37〕 explored the relationship between supplier management, customer relations and organizational performance, and used purchasing, quality, customer relations and relationship supplier closeness (C3) to evaluate the suitability of a supplier selection model. Sarkis〔31〕 categorized environmentally conscious business practices into five major components including green design (C8), product life cycle analysis (C17), the total quality of environmental management (C18) and compliance with environmental standards such as ISO 14000 (C11) 〔8〕〔20〕〔24〕.

Researchers have included internal green production (C12), clean production (C14) and the quality of internal service (C7) as GSCM criteria, and the supplier's purchasing perspective has also been addressed 〔13〕〔15〕〔36〕. Carr and Smeltzer 〔4〕 documented how firms with strategic purchasing plans foster long-term, cooperative relationships, and achieve greater responsiveness to the needs of their suppliers. Zhu and Geng 〔55〕 studied Chinese firms and examined their methods of environmental development in business practices such as green purchasing (C9). Among the supplier selection models currently in use, environmentally preferable bidding and life cycle assessment (C10), which assesses the impacts of green purchasing and their financial consequences through the entire product life-cycle, are the most popular. However, supplier flexibility (C6) is a complex and multi-dimensional capability that requires firm-wide effort to increase the firm's responsiveness, reduce waste and limit the firm's environmental impact 〔11〕. Chen *et al.*〔7〕 identified many quantitative and qualitative factors such as quality, price and flexibility, and concluded that delivery performance must be considered in the determination of the optimal supplier. Humphreys *et al.* 〔18〕 identified environmental criteria that influence a firm's management support services (C13) and developed knowledge-based environmental management system requirements (C16) to integrate the environmental criteria and support the supplier selection process.

GSCM capabilities are ''complex bundles of individual skills, assets and accumulated knowledge exercised through production processes, that enable firms to co-ordinate activities and make use of their resources'' 〔26〕〔3〕〔56〕. Moreover, GSCM is essential to the competitive advantage of a firm. GSCM involves the flow of finances, logistics, and information, as well as the ability to integrate relationships and green technology (C4), and to reduce the use of hazardous products in the production process (C15).

In summary, this study uses 18 criteria in qualitative scales to evaluate the suppliers in uncertainty. This study considers GSCM in PLCA practices to analyze in fuzzy hybrid MCDM technique and assists the evaluators in choosing one or few most appropriate alternatives with a finite set of criteria.

3 Methods

There are fundamentals used in the proposed method are addressed such as ISM, fuzzy set theory and ANP. These fundamentals used to clarify the hierarchical structure among the criteria, determine the fuzzy weight for each criterion, determine the structure with the dependence criteria, and the proposed hybrid method in calculating the synthetic utility.

3.1 Interpretive structural modeling

The concept and detailed methodology of ISM was first introduced by Warfield 〔51〕 as a computer-assisted methodology to identify and construct the inter-relationships of different elements within a complex system or issue. This method is interpretive since the inputs for the criteria list and their pair-wise relations are decided through expert interviews and group judgments, is structural because the overall order structure is extracted based on the relationships among criteria within the set, and is modeling as the specific relationships and hierarchical structure are portrayed in a graphic model. The most remarkable contribution of this method is to provide a systemic insight of the complicated system through graphics and words 〔25〕. Hence, ISM has been widely used to effectively identify and understand the mutual influences among specific criteria within an issue. ISM is advantageous since it does not require any prior knowledge of the entire system and effectively provides a means to present a ranking order on the complexity of interactions as well as classify criteria into various categories depending upon their driver and dependence power.

The method is based on discrete mathematics, graph theory, social sciences, group decision-making, and computer assistance. The step consequences are conducted based on Warfield 〔51〕 and Agarwal *et al.* 〔1〕. The initial step begins with the identification of relevant criteria using group problem-solving technique, and then a Structural Self-Interaction Matrix (SSIM) 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. The next step is the partitioning of the criteria into different levels based on assessing the reachability and antecedent sets for each criterion, followed by the development of the interactive matrix. Then, the marix is converted into a hierarchical model by replacing the criteria nodes with statements. The extracted structural model is reviewed to check for conceptual inconsistency and needed modifications. The logical procedure of this study is demonstrated in Figure 1 which follows Singh *et al.* 〔34〕 general model of ISM.

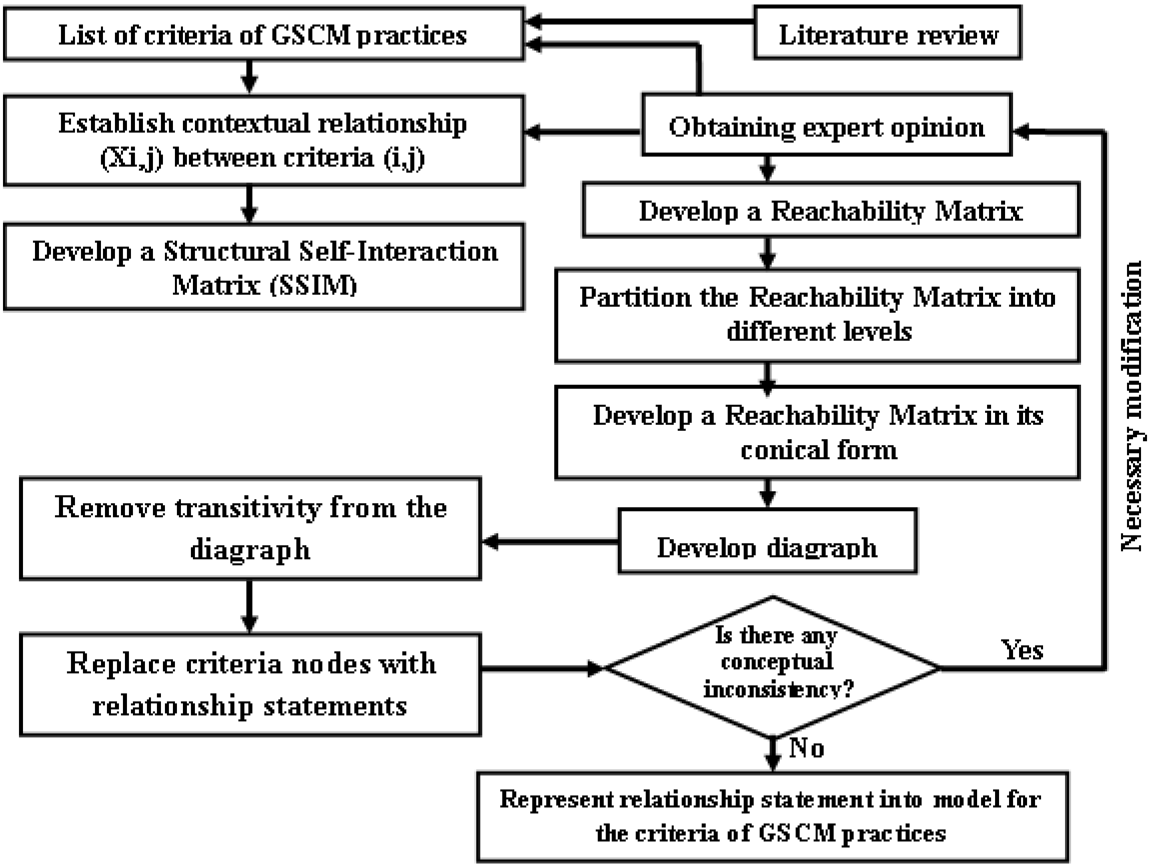


Figure 1. ISM flow

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 particular relation obviously distinguishes this method from a mere aggregation of criteria. A relation matrix can be formed using questions like "Does the feature e_i inflect the feature e_j ?".

The reachability matrix can be calculated using equations (1) and (2) as follows:

$$M = D + I \tag{1}$$

$$M^* = M^k = M^{k+1} \quad k>1 \tag{2}$$

The reachability and the priority set are then calculated bases on Eqs. (3) and (4), respectively, as presented below. Notes that m_{ij} denotes the value of the ith row and the jth column.

$$A\ (t_i) = \{\ t_j \,|\, m'_{\ ij} = 1\} \tag{3}$$

$$R\ (t_i) = \{\ t_j \,|\, m'_{\ ij} = 1\} \tag{4}$$

$$R\ (t_i) \cap A\ (t_i) = R\ (t_i) \tag{5}$$

According to the equation (5), the levels and relations among the criteria can be determined. In addition, the criterion's relations can be structurally and systematically expressed using the graph in which ***R*** represents the intersection of antecedent set and reachability set. The reachability matrix transforms the each entry of the linguistic preferences into 1s and 0s. The situations are as follows:

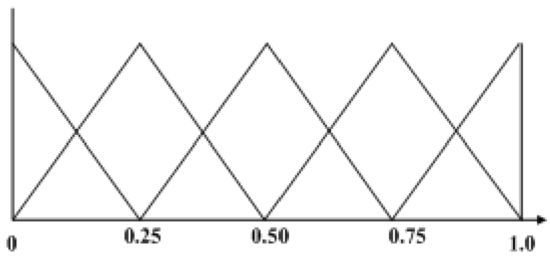
- If the *(i, j)* described is A, the *(i, j)* described in the reachability matrix becomes 1 and the *(j, i)* entry becomes 0.
- If the *(i, j)* described is B, the *(i, j)* described in the matrix becomes 0 and the *(j, i)* entry becomes 1.
- If the *(i, j)* described is C, the *(i, j)* described in the matrix becomes 1 and the *(j, i)* entry also becomes 1.
- If the *(i, j)* described is D, the *(i, j)* described in the matrix becomes 0 and the *(j, i)* entry also becomes 0. Following these rules, initial reachability matrix for the criteria is established.

3.2 Fuzzy set theory

The proposed method uses the linguistic preferences for deriving the priorities of different selection alternatives and setting up TFNs in all aspects, criteria and alternatives due to the uncertainty involved in this study. The fuzzy set theory 〔54〕 is a mathematical theory designed to model the fuzziness of human cognitive processes.

Table 1. Linguistic preferences

Linguistic preferences	Linguistic values
Extreme importance	(0.75, 1.0, 1.0)
Demonstrated importance	(0.5, 0.75, 1.0)
Strong importance	(0.25, 0.5, 0.75)
Moderate importance	(0, 0.25, 0.5)
Equal importance	(0, 0, 0.25)



Triangular fuzzy membership functions

The expert uncertain judgment represented as a set of fuzzy numbers. A triangular fuzzy number is a special kind if fuzzy number whose membership function is defined by three real numbers (l,m,u) . The membership function is illustrated in Fugure 1 and described below (Cox, 1995).

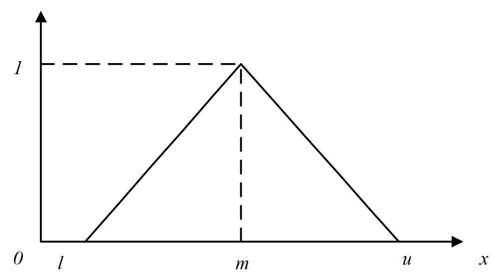


Figure 2. TFN A=(*l*,*m*,*u*)

Thus, *l, m,* and *u* are the lower, mean and upper bounds of the triangular fuzzy number. The membership function *u* represents the degree to which any given element x in the domain X belongs to the fuzzy number A. The expert judgments are as expressed as TFNs, the triangular fuzzy comparison matrix is

$$\tilde{A} = (\tilde{a}_{ij})_{nxn} \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ & \vdots & \ddots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & (1,1,1) \end{bmatrix}, \quad (6)$$

Where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and $\tilde{a}_{ij}^{-1} = (1/l_{ij}, 1/m_{ij}, 1/u_{ij})$ for $i,j = 1,\ldots\ldots,n$ and $i \neq j$

A fuzzy weighted sum matrix (M) can be derived for the alternatives by multiplying the fuzzy weight vector related to criteria with the decision matrix for alternatives under each criteria, and summing the obtained vectors.

$$\tilde{M} = \begin{bmatrix} (l_1, m_1, u_1) \\ (l_2, m_2, u_2) \\ \cdots\cdots \\ (l_n, m_n, u_n) \end{bmatrix} \quad (7)$$

Where n= the number of alternatives.

The defuzzification is according to Tseng 〔41〕 compares two fuzzy numbers A and B in terms of their α-cuts $A_\alpha = [a_{\alpha-}, a_{\alpha+}]$ and $B_\alpha = [b_{\alpha-}, b_{\alpha+}]$. The intervals given are the upper and lower bounds within which the membership functions of A and B are greater than or equal to α. A is smaller than B, denoted $A \leq B$ $a_{\alpha-} < b_{\alpha-}$ and $a_{\alpha+} < b_{\alpha+}$ for all α in the interval [0, 1]. The α-cut method accounts for uncertainty in the fuzzy ranges chosen. In this case, the more a-cuts are examined, the more reliable results are achieved. The α-cut can be applied to transform the total weighted evaluated matrices into interval matrices, which provide α*l* and α*u* for each alternative as follows:

$$\tilde{M}_\alpha = \begin{bmatrix} (\alpha l_1, \alpha u_1) \\ (\alpha l_2, \alpha u_2) \\ \cdots\cdots \\ (\alpha l_n, \alpha u_n) \end{bmatrix} \quad \ldots\ldots\ldots (8)$$

$$\alpha l = \alpha\ x\ (m - l) + l \quad (9)$$

$$\alpha u = u - \alpha\ x\ (u - m) \quad (10)$$

To convert the interval matrices into crisp values, this is done by applying the epsilon function, which also represents the perceptions of the management. The managements with optimistic moderate and pessimistic perceptions take on a upper, medium, or lower bound epsilon values in the range [0, 1] respectively:

$$C_\varepsilon = \begin{pmatrix} C_{\varepsilon 1} \\ C_{\varepsilon 2} \\ \cdots\cdots \\ C_{\varepsilon n} \end{pmatrix} \quad (11)$$

$$C_\varepsilon = \varepsilon\ x\ \alpha u + (1 - \varepsilon) x\ \alpha l \quad (12)$$

Where, the C_ε are crisp values corresponding to epsilon. These values should be normalized to similar scales.

3.3 Analytical network process

ANP is a generalization of the analytical hierarchical process (AHP) 〔29〕〔41〕〔38〕. While AHP represents a framework with a unidirectional hierarchical AHP relationship, ANP allows for complex interrelations among decision levels and criteria. The ANP feedback approach replaces hierarchies with networks in which the relations among levels are not easily represented as higher, lower, dominant or subordinate. Given the problems encountered in reality, a dependent and feedback relationship is usually generated among the criteria and such interdependence relations usually become more complex with the change in scope and depth of the decision-making problems. Figure 3 is presented a close loop framework with dependence relations, which applied in this study ANP feedback approach.

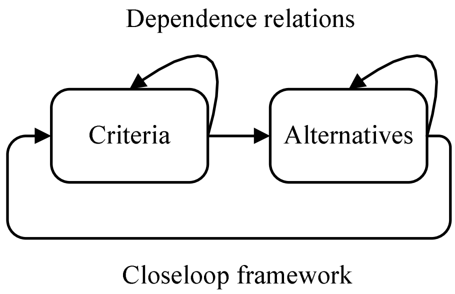


Figure 3. ANP closeloop framework

ANP uses a supermatrix to deal with the relations of feedback and dependence among the criteria. If no interdependent relationship exists among the criteria, then the pairwise comparison value would be 0. If an interdependence and feedback relationship exists among the criteria, then such values would no longer be 0, and an unweighted supermatrix M will be obtained. If the matrix does not conform to the principle of column stochasticity, the decision maker can provide the weights to adjust the matrix into a supermatrix that conforms to the principle of column stochasticity, producing a weighted supermatrix M. The limited weighted supermatrix M* is based on Eq. (15) and allows for gradual convergence of the interdependence relations to obtain the accurate relative weights among the criteria. The following equations are applied in this study.

In testing for the consistency of a judgment matrix, acceptable matrix results have consistency index (C.I) and consistency ratio (C.R.) values less than 0.1 and the C.I. of a judgment matrix can be obtained by

$$CI = \frac{\lambda_{\max} - n}{n-1}. \qquad (13)$$

When $\lambda_{max} = 0$, complete consistency exists within judgment procedures. When $\lambda_{max} = n$, the C.R. of C.I. to the mean random consistency index R.I. is expressed as C.R. The equation as follows

$$CR = \frac{CI}{RI} \qquad (14)$$

$$M^* = \lim_{k \to \infty} M^k \qquad (15)$$

ANP is a mathematical theory that can deal with multiple dependencies systematically. The merits of ANP in group decision-making are as follows〔12〕〔40〕: (i) both tangibles and intangibles, individual values, and shared values can be included in the decision process; (ii) the discussion in a group can be focused on objectives rather than on alternatives; (iii) the discussion can be structured so that every factor relevant to the decision is considered; and (iv) in a structured analysis, the discussion continues until relevant information from each individual member in the group is considered and a consensus is achieved.

3.4 Proposed hybrid method

Step 1. The ISM is utilized to gain a hierarchical structure model, it is necessary to consult a group of experts to confirm reliable information of the criteria influences and directions applying in equations (1)~(5).

Step 2. The fuzzy assessments interpret the linguistic preferences into fuzzy linguistic scale and converts the triangular fuzzy numbers into crisp may score, the fuzzy assessments are defuzziffied and aggregated as a crisp value ($\tilde{M}_{\alpha}$).

Step 3. The crisp value can be composed a pairwise comparison matrix and decompose the matrix with MATLAB 6.5 to acquire the eigenvector. Moreover, the eigenvector must be normalized into local priority for composing the unweighted supermatrix. In testing for the consistency of judgment matrix, the consistency index (C.I.) of a judgment matrix can be obtained using Eq.(13) and acquire the λ_{max} value in the process of decomposed the pairwise comparison matrix. In addition, when $\lambda_{max} = 0$, complete consistency exists within judgment procedures. When $\lambda_{max} = n$, the consistency ratio (C.R.) of C.I. to the mean random consistency index R.I. is expressed as C.R. using Eq. (14).

Step 4. Analyze the proposed method in decision objectives, the crisp value is composed the unweighted supermatrix. The result can obtain the normalized unweighted supermatrix from the multiplied result and raises to limiting powers to calculate the overall priority weights using Eq. (15).

4 Results

This section uses an empirical example of a printed circuit board (PCB) manufacturing firm to demonstrate that the integrated fuzzy MCDM technique is more appropriate than the traditional method, especially when criteria are dependence. This section is divided into two subsections: case information and analysis. To illustrate the utility of the proposed evaluation method, the model was applied to a PCB manufacturing firm. The firm continues to improve its manufacturing processes and faces the challenges of environmental management and SCM. To deal with the requirements of supplier selection, the firm must implement GSCM criteria from relevant environmental regulations. Hence, the firm created an expert team consisting of ten professors, five vice presidents and five management professionals with five years extensive experience.

4.1 Case information

The firm is the largest professional PCB and original equipment manufacturer (OEM) in Taiwan and is the fifth ranked producer in the world. To offer the best services, the firm is continuing to develop next generation green technology, enhance their competitiveness and satisfy green customer demands. Due to the firm continues to develop green products and new green technologies to comply with customer green requirements, the firm has to sustain in a competitive market, proper GSCM is essential. The chief executive officer wants to understand the importance role of GSCM, this study was presented to the expert group for the evaluation in complying with the requirement outlined in RoHS and WEEE directives. The firm benefited from this evaluation by acquiring purchasing orders from the USA and the European Union. Therefore, this study, the firm's four green suppliers were analyzed according to identify an analytical and systematic method of evaluating the management procedures of the suppliers. To select the optimal supplier, the experts should adopt the proposed hybrid technique to the proposed criteria evaluation. This analysis outlined in this paper would provide recommendations to the firm and would be useful for efficient and effective GSCM implementation.

4.2 Analysis

This study attempts to apply the ANP to the evaluation of eighteen criteria in uncertainty. The study objective is to analysis the GSCM criteria using ISM, fuzzy set theory and ANP technique. The proposed criteria are as follows: (C1) reliability of delivery; (C2) profitability of the supplier; (C3) relationship to the supplier; (C4) green technology capabilities; (C5) conformance quality; (C6) flexibility of the supplier; (C7) service quality; (C8) green purchasing capabilities; (C9) life cycle assessment; (C10) green design; (C11) green certifications; (C12) internal green production plans; (C13) management support; (C14) green production; (C15) the reduction of hazardous materials in the production process; (C16) environmental management systems; (C17) product life cycle assessment; (C18) total quality environmental management. The expert group followed the application solution with the four-phase procedures.

Step 1. 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, shown in Table 2. Meanwhile, the antecedent set is composed of the element itself and other criteria that may help achieve it. The intersection of these sets is derived for all the criteria. The criteria which 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 their level. After the top-level criteria are identified and removed from the rest of the criteria. The process is repeated to find the criteria in the next levels. The final hierarchical model is developed. The criteria along with their reachability sets, antecedent sets, and intersection sets and the identified levels are shown in Table 3. The segregate result of hierarchical structure are with four levels, level I includes six criteria (C2, C3, C5, C10, C11, C12), level 2 is with four criteria (C6, C7, C8, C9), there are four criteria in level III (C1, C9, C16, C17) and last four criteria are located in level IV (C4, C8, C14, C18).

Table 2. Reachability matrix

Criteria	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13	C 14	C 15	C 16	C 17	C 18
C 1	1	1	0	0	1	0	1	0	1	1	1	1	1	0	1	1	1	1
C 2	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0
C 3	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0

C 4	1	1	0	1	0	0	1	0	1	1	1	1	1	1	1	1	1	1
C 5	0	1	1	0	1	0	0	0	1	1	0	1	0	1	0	0	0	0
C 6	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1
C 7	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	0	0	0
C 8	1	0	1	1	1	0	0	1	1	1	1	1	1	1	0	0	0	0
C 9	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
C 10	0	1	1	1	0	1	1	1	0	1	1	0	1	0	1	0	0	0
C 11	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1
C 12	1	1	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	1
C 13	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0
C 14	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
C 15	1	1	0	1	0	0	0	0	1	0	1	1	1	1	1	0	0	0
C 16	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1
C 17	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	1	1
C 18	1	1	1	1	1	0	0	0	1	0	1	0	1	1	1	0	0	1

Table 3. Hierarchical structure levels

Criterion (C_i)	Reachability set: R (C_i)	Antecedent set: A (C_i)	Intersection R (C_i) ∩ A (C_i)	Level
C 1	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 15	1, 3, 4, 5, 7, 8, 9, 11, 12, 13,14,15,16,17,18	1, 3, 4, 5, 7, 9, 11, 12,15	III
C 2	2, 3, 4, 5, 10, 11, 12,17,18	1, 2, 3, 4, 5, 10, 11, 12	2, 3, 4, 5, 10, 11, 12	I
C 3	6, 7, 9, 10, 11, 12	6, 7, 9, 10, 11, 12	6, 7, 9, 10, 11, 12	I
C 4	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 16	1, 2, 3, 4, 5, 10, 11, 12, 16	1, 2, 3, 4, 5, 10, 11, 12,16	IV
C 5	4, 5, 6, 7, 9, 10, 11, 12	4, 5, 6, 7, 8, 9, 10, 11, 12	4, 5, 6, 7, 9, 10, 11, 12	I
C 6	3, 5, 6, 7, 10, 11, 12, 13,14,15,16,17,18	1, 3, 4, 5, 6, 7, 8, 9, 10, 13, 18	3, 5, 6, 7, 10, 13, 18	II
C 7	1, 7, 8, 9, 10, 11, 12, 15, 16	1, 3, 4, 5, 6, 7, 8, 9, 10, 15,16	1, 7, 8, 9, 10, 15,16	II
C 8	1, 5, 6, 7, 8, 10, 11, 12	7, 8, 13,14,15,16,17,18	7, 8	IV
C 9	1, 3, 5, 6, 7, 9, 10, 11, 12	1, 3, 4, 5, 7, 9, 10, 11, 12	1, 3, 5, 7, 9, 10, 11, 12	III
C 10	2, 3, 4, 5, 6, 7, 11, 12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	2, 3, 4, 5, 6, 7, 11, 12	I
C 11	1, 2, 3, 4, 5, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 9, 10, 11, 12	I
C 12	1, 2, 5, 9, 12	1, 2, 3, 4, 5, 6, 7, 8, 9 , 12	1, 2, 3, 4, 5, 9, 12	I
C 13	1, 2, 3, 4, 5, 11, 12, 17	2, 3, 4, 17, 18	2, 3, 4, 17	II

C 14	1, 2, 3, 4, 5, 9, 10, 11, 12	5, 9, 10, 11, 13, 15, 16	5, 9, 10, 11	IV
C 15	3, 4, 5, 9, 12, 16,17,18	1, 2, 4, 9, 12, 16	4, 9, 12, 16	II
C 16	1, 2, 10, 11, 12	1, 2, 3, 4, 5, 10, 11, 12, 16	1, 2, 10, 11, 12	III
C 17	1, 2, 3, 10, 11, 12,17,18	6, 7, 8,10, 11, 12,17,18	10, 11, 12, 17, 18	III
C 18	4, 5, 9, 10,18	1, 2, 4, 10,18	4, 10,18	IV

Step 2. The 18 criteria and four alternatives were measured in the TFNs. The defuzzification process employed Eqs. (6) - (12). The TFNs were applied to transform the total weighted performance matrices into interval performance matrices, providing αl and αu .Using Eq. (9) and (10), C_ε was transformed into crisp values corresponding to Epsilon values on comparable scales. Therefore, Linguistic preferences were used to convert measures into TFNs (shown in Table 1), and the TFNs were converted into crisp values. Table 4 presented the fuzzy synthetic evaluation of 20 experts evaluated in linguistic preferences. For alternatives under C2's pair comparison, the total weighted performance matrix was constructed using Eq. (9). Eq. (10) was applied to arrive at the αl and αu. For instance, αl = 0.5 x (7.632 – 6.235) + 6. 235 = 6.94, and αu = 8. 735 – 0.5 x (6. 235 –7.632) = 8.18. Lastly, the crisp value C_ε was computed using Eq. (12). The completed results were shown in Table 4.

Table 4. Example of fuzzy synthetic evaluation under C2

C2's Pair comparison		(l,	m,	u)	αl	αu	C_ε
(A1,	A2)	(6. 235,	7.632,	6. 235)	6.94	8.18	7.56
	A3)	(1.106,	1.225,	1.363)	1.166	1.294	1.23
	A4)	(1.243,	1.342,	1.453)	1.293	1.398	1.345
(A2,	A3)	(6.837,	7.348,	7.858)	7.093	7.603	7.348
	A4)	(1.291,	1.414,	1.558)	1.353	1.486	1.419
(A3,	A4)	(7.433,	7.937,	8.441)	7.685	8.189	7.937

Step 3. To acquire the eigenvector [0.618, 0.512, 0.389, 0.238], the eigenvector needs to be normalized into local priorities for composing the unweighted supermatrix, the local priority weights was [0.352, 0.291, 0.221, 0.135]. For evaluating the consistency of the judgment matrix, the C.I. was 0.087 and the C.R. was 0.075, using Eqs. (13) and (14), which is lower than the 0.1 cutoff. The pair comparisons were repeated to complete the weights to compose the unweighted supermatrix according to the relations recorded on reachability matrix, shown in Table 2. The unweighted supermatrix presented in Table 6. However, the columns may not be column-stochastic (i.e., they may not sum to one). Transformations may be required for the columns to become column-stochastic and thus minimize the possibility of divergence to infinity or convergence to zero. For instance, the whole unweighted matrix

needed to be multiplied by 0.5 because the sum of the unweighted supermatrix was 2.

Table 5. Criteria pair comparison after defuzzification (in C2)

C2	A1	A2	A3	A4	e-vector	Weights
A1	1.000	6.928	1.230	1.345	0.618	0.353
A2	0.144	1.000	7.348	1.419	0.512	0.291
A3	0.813	0.136	1.000	7.937	0.389	0.221
A4	0.743	0.705	0.126	1.000	0.238	0.135

Notes: C.I.= 0.087; C.R. = 0.075

Step 4. The normalized unweighted supermatrix were obtained from the multiplied result and raised to limiting powers to calculate the overall priority weights using Eq. (15), shown in Table 7. $W_{\text{weights of criteria}}$ = (C2, C3, C5, C10, C11, C12, C6, C7, C13, C15, C1, C9, C16, C17, C4, C8, C14, C18) = (0.028, 0.019, 0.024, 0.026, 0.032, 0.033, 0.028, 0.027, 0.029, 0.024, 0.027, 0.029, 0.027, 0.030, 0.030, 0.029, 0.035, 0.026). $W_{\text{weights of alternatives}}$ = (A1, A2, A3, A4) = (0.136, 0.119, 0.104, 0.141). The internal green production plans (C12) presented the most important criteria due to its weight (0.033). The ranking of the alternatives was as follows: Alternative 4(0.141) > Alternative 1 (0.136) > Alternative 2 (0.119) > Alternative 3 (0.104)

Table 6. Unweighted supermatrix (Closeloop relations)

	C2	C3	C5	C10	C11	C12	C6	C7	C13	C15	C1	C9	C16	C17	C4	C8	C14	C18	A1	A2	A3	A4
C2	0.085	0.087	0.000	0.000	0.085	0.068	0.000	0.000	0.096	0.048	0.066	0.000	0.119	0.166	0.000	0.000	0.068	0.000	0.072	0.048	0.068	0.063
C3	0.000	0.092	0.000	0.000	0.000	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.096	0.103	0.000	0.052	0.065	0.042	0.063
C5	0.067	0.052	0.158	0.125	0.000	0.061	0.000	0.000	0.000	0.000	0.075	0.086	0.000	0.000	0.000	0.000	0.096	0.000	0.042	0.068	0.081	0.048
C10	0.075	0.078	0.000	0.043	0.048	0.000	0.204	0.085	0.088	0.069	0.043	0.000	0.000	0.000	0.096	0.093	0.000	0.000	0.047	0.053	0.051	0.044
C11	0.039	0.056	0.105	0.000	0.072	0.088	0.218	0.042	0.086	0.072	0.056	0.000	0.095	0.128	0.085	0.075	0.049	0.156	0.065	0.032	0.049	0.042
C12	0.042	0.072	0.000	0.088	0.045	0.066	0.208	0.000	0.000	0.086	0.085	0.047	0.048	0.109	0.205	0.048	0.052	0.105	0.063	0.048	0.067	0.046
C6	0.044	0.061	0.085	0.053	0.053	0.052	0.048	0.056	0.052	0.058	0.056	0.051	0.000	0.058	0.109	0.055	0.000	0.129	0.058	0.055	0.055	0.057
C7	0.095	0.085	0.055	0.075	0.042	0.000	0.000	0.125	0.000	0.085	0.046	0.046	0.000	0.000	0.096	0.063	0.068	0.000	0.051	0.038	0.068	0.069
C13	0.066	0.000	0.000	0.047	0.052	0.049	0.060	0.175	0.069	0.000	0.065	0.095	0.253	0.042	0.000	0.125	0.068	0.000	0.062	0.052	0.043	0.046
C15	0.066	0.000	0.000	0.000	0.047	0.063	0.000	0.062	0.053	0.063	0.058	0.089	0.000	0.000	0.051	0.000	0.055	0.000	0.075	0.075	0.055	0.054
C1	0.044	0.000	0.178	0.089	0.075	0.085	0.000	0.065	0.045	0.086	0.052	0.045	0.063	0.042	0.000	0.000	0.000	0.096	0.045	0.047	0.044	0.075
C9	0.050	0.046	0.000	0.052	0.051	0.068	0.157	0.000	0.048	0.048	0.049	0.096	0.052	0.153	0.052	0.085	0.053	0.085	0.052	0.048	0.053	0.051
C16	0.075	0.088	0.091	0.051	0.086	0.065	0.000	0.000	0.063	0.085	0.071	0.063	0.096	0.000	0.053	0.000	0.051	0.070	0.056	0.051	0.051	0.049
C17	0.047	0.042	0.058	0.175	0.074	0.075	0.000	0.000	0.090	0.096	0.085	0.041	0.000	0.036	0.045	0.000	0.042	0.063	0.067	0.096	0.067	0.041
C4	0.085	0.000	0.000	0.067	0.068	0.084	0.000	0.205	0.086	0.047	0.051	0.095	0.152	0.098	0.096	0.000	0.066	0.041	0.029	0.047	0.054	0.078
C8	0.000	0.067	0.098	0.051	0.044	0.046	0.000	0.000	0.062	0.000	0.000	0.048	0.000	0.000	0.059	0.254	0.096	0.000	0.059	0.063	0.085	0.066
C14	0.059	0.092	0.000	0.085	0.085	0.096	0.105	0.185	0.085	0.081	0.053	0.093	0.123	0.168	0.000	0.106	0.085	0.125	0.059	0.049	0.042	0.050
C18	0.061	0.082	0.172	0.000	0.072	0.000	0.000	0.000	0.078	0.076	0.088	0.105	0.000	0.000	0.053	0.000	0.048	0.129	0.046	0.065	0.025	0.058
A1	0.355	0.241	0.348	0.355	0.249	0.349	0.150	0.162	0.249	0.351	0.251	0.358	0.355	0.141	0.248	0.355	0.149	0.249	0.352	0.259	0.158	0.505
A2	0.135	0.550	0.125	0.214	0.119	0.144	0.247	0.352	0.158	0.118	0.178	0.281	0.145	0.325	0.251	0.146	0.359	0.421	0.157	0.364	0.459	0.152
A3	0.152	0.052	0.224	0.166	0.348	0.125	0.243	0.211	0.333	0.167	0.252	0.215	0.214	0.255	0.175	0.247	0.251	0.139	0.108	0.175	0.137	0.163
A4	0.358	0.157	0.303	0.265	0.284	0.382	0.360	0.275	0.260	0.365	0.319	0.146	0.286	0.279	0.326	0.252	0.241	0.191	0.383	0.202	0.246	0.180

Table 7. Converged supermatrix

	C2	C3	C5	C10	C11	C12	C6	C7	C13	C15	C1	C9	C16	C17	C4	C8	C14	C18	A1	A2	A3	A4
C2	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
C3	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
C5	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
C10	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
C11	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
C12	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
C6	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
C7	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
C13	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.028	0.029	0.028	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.028
C15	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
C1	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
C9	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	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
C16	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
C17	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
C4	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
C8	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	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
C14	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
C18	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
A1	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136
A2	0.119	0.120	0.120	0.119	0.119	0.119	0.119	0.119	0.119	0.120	0.119	0.119	0.119	0.120	0.120	0.120	0.119	0.120	0.120	0.120	0.120	0.119
A3	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104
A4	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141

5 Managerial Implications

The framework can be used to evaluate the impact of various supplier selection and can provide a mechanism of monitoring and establishing evaluation platforms for firms in the GSCM activities. In prior studies, the firm's GSCM procedures were highly variable; however, a clear link to the firm's decision was not observed. Indeed, the analyses presented in previous studies were based on only a few variables, and self structural models were not sufficient at explaining hierarchical structure GSCM criteria in nature. These results indicate that GSCM is a multi-criteria concept based on upstream or downstream selection in the supply chain. When evaluating the impact of a firm's GSCM activities, the overall enhancement in product life cycle assessment and its effect on the organization must be considered.

The proposed framework with 18 criteria allows managers and researchers to better understand the differences in operations, PLCA activities and specific management interventions. The framework allows the 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) is represented the overall importance of the evaluator's perception to the four alternatives. Here, the top five criteria and corresponding values were: green production (C14- 0.035); internal green production plans (C12- 0.033); green certifications (C11- 0.032); green technology capabilities (C4- 0.30); green purchasing capabilities (C8- 0.029). The result presents the green issue is important on the supplier selection process. The result is similar to the study of Zhu *et al.* 〔58〕and Tseng *et al.* 〔44〕 in terms of GSCM practices.

Moreover, the GSCM criteria were analyzed by the experts, and the performance of the supplier was determined primarily by the green concept applied in the operations process and management support. The perceived benefits to customers or suppliers, and internal benefits affect the use of electronically-enabled supply chains. Tseng *et al.* 〔42〕 studied sustainable production indicators, and found that two major criteria contributed to sustainable production, including a reduction in waste generated by suppliers and a reduction in the amount of hazardous waste generated by the supplier. In a broader sense, the framework can be used as an analytical tool to develop and construct a strategic environmental development plan and GSCM criteria for the firm. To achieve optimal results, managers should understand the firm's GSCM evaluation criteria, including the presence of building hierarchical structure, linguistic preferences and dependence relations in nature.

This study proved that the manager must be aware to capture a fairly complete picture of the firm's GSCM. In other words, managers may find that the fuzzy hybrid MCDM technique for the assessment of GSCM criteria is a useful method for reviewing and improving strategic green plans and green performance evaluations, which may lead to enhanced green operations and competitive advantage. For firms that intend to evaluate suppliers with the proposed criteria, this study offers several benefits. The main contribution of this study is the hierarchical model presented in Table 3. This technique provides a structured and logical method of synthesizing judgments to the evaluation of appropriate suppliers. This study is a useful guideline that helps structure a difficult and often emotional decision. The second benefit is the development of criteria based on a comprehensive review of GSCM in PLCA.

The proposed technique and criteria provide an overview of a firm's decision-making process in the presence of multi-situations in contemporary sustainable management issue. Moreover, firms can better understand the evaluation GSCM criteria in PLCA issue. The hybrid technique is particularly useful for making decisions based on multiple criteria in the presence of management status in hierarchical structure, dependence relations and uncertainty. Nevertheless, the framework can be customized and used for the GSCM activities and selection of suppliers. To apply the proposed methodology, the evaluator must remove irrelevant criteria and include criteria that are applicable to their firm. Hence, a firm's GSCM can be based on many different types of criteria and can be modified and refined as necessary.

6 Concluding Remarks

This study focused on the development of a hierarchical structures using ISM, expresses the uncertainty of the model with fuzzy set theory, handling dependence relation among criteria applied ANP, the results of the proposed method reflected these dependences, uncertainties and were highly reliable. Ultimately, to achieve optimal results, the criteria must be considered and evaluated simultaneously. The proposed method was employed to evaluate the GSCM model, which are often inaccurate or uncertain. Moreover, by transforming linguistic expressions into crisp values, the hierarchical model allows an evaluator to utilize qualitative and imprecise quantitative criteria. To employ multi-criteria based on subjective judgments, this study applied TFNs to represent linguistic preferences, which reduced cognitive burden during the evaluation process. The defuzzification method was employed to obtain a final weighting of each criterion. The proposed criteria, needs to incorporate with hierarchical structure in nature and fuzzy theory to obtain an effective method for the determination of weights from subjective judgments. This method is also useful for evaluating the GSCM practices of a firm.

Hence, this study proposed a proposed technique for selecting alternatives in the presence of uncertainty. However, the evaluator's judgment is often uncertain, and in hierarchical structure cannot always be evaluated in prior studies. An empirical example of green supplier selection uses fuzzy hybrid MCDM and illustrate the application of the proposed criteria in an OEM 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 validated criteria. The model establishes a foundation for future study and is appropriate for predicting uncertain criteria. To improve the firm's performance and provide information that will have the greatest effect on reducing uncertainty, a firm can apply this model to evaluate and determine the optimal GSCM supplier.

This framework shows that more generic, situational characters like the number of suppliers available, the historic GSCM 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 which need further research. First, this study was designed to evaluate the case PCB firm's GSCM in PLCA and supplier selection problem. Different groups of firms may have different decision-making processes, such as different scale and industrial sectors et al. It might be meaningful to test the proposed model by considering the effects of more firms' characteristics for future studies. Second, the measures were somewhat in myopia. It would be better to recommend included a longitudinal study. Lastly, it can be also an interesting extension to examine the grey system in the decision-making process in the future research.

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