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Evaluating Green Supply Chain Management with Incomplete Information

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ABSTRACT

There has been a growing interest in firms' environmental sustainability activities to improve environmental practices in their supply chain. This study aims to deal with supplier evaluation of firm's green supply chain management (GSCM) criteria with incomplete information. Nevertheless, the suitable supplier is a key strategic direction in eliminating environmental impact on supply chain management for manufacturing firms. The firm's GSCM criteria and supplier selection need to be unified as a system to improve the firm's performance.

Keywords: Grey Relational Analysis, Firm's Green Supply Chain Management

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1. INTRODUCTION

Environmental management has evolved to include boundary-spanning activities in supply chain in Taiwan's electronic industry. All of these activities are related to green supply chain management (GSCM), whether upstream with the suppliers or downstream with the customers (Lee *et al*., 2009). European Union has set a range of environmental policies such as the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) and waste electronics and electrical equipment (WEEE) directives. The directives ban manufacturers, sellers, distributors and recyclers on selected waste electrical and electronic equipment and certain hazardous substances, (Tseng, 2009, 2010a). The WEEE is aimed at the life cycle of product, and RoHS is exploited during the design stage of products. While there are environmental regulations and mandatory programs, pressures to protect the environment come from other external stakeholders. However, the limited understanding of GSCM in environmental and non-environmental criteria has hampered the development of a widely accepted framework that would characterize and categorize firm's supply chain management (SCM) activities.

Nevertheless, various studies can be found in the literatures (Zhu *et al*., 2008; Srivastava, 2007). Srivastava (2007) describes GSCM as combining environmental thinking and SCM and defines it as including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumer, and end-of-life management of the product after its useful life. Moreover, the firms have extensive supplier selection under their performance evaluation, and tend to leverage staff resources throughout the firm to eliminate the environmental impacts (Tseng *et al*., 2009a, 2010b). Firms typically expect their suppliers to go beyond environmental compliance and undertake efficient, green product design and life cycle assessment activities. Hence, the firms' supplier alternatives must satisfy the GSCM criteria under the constraint of incomplete information and human subjective preferences, and this phenomenon has rarely been thoroughly examined.

GSCM philosophy focuses on how firms utilize their suppliers' processes, technology and capability, and integrating environmental concerns, to enhance its competitive advantage. To practice in GSCM, identification of appropriate measures is necessary to complete robust study and to advance the body of knowledge in a field, both academically and practically. Academically, to effectively and empirically advance a theory within this field, there is greater attention to be focused on employing multi-criteria, assessing the criteria for content validity and purifying them through extensive literatures reviewing (Zhu *et al*., 2008; Srivastava, 2007; Tseng *et al*., 2009b; Lee *et al*., 2009). Therefore, this study integrates a number of criteria that may be used to help evaluate practices in GSCM reviewing the literatures in supply chain and environmental management (Tseng *et al*., 2008, 2009b; Zhu *et al*., 2008; Srivastava, 2007; Lee *et al*., 2009). Practically, firms can benefit from the development of reliable and valid criteria to practices implementation. The practitioner applies these criteria for benchmarking and continuous improvement when seeking to harmonize environmental and SCM together. One contribution of this study is to help firms understand the different criteria in their implementation. However, the field of GSCM is valuable arguably in its optimal supplier selection while the environment is with imprecise and incomplete information. In order to solve this phenomenon, the multi-criteria decision making (MCDM) tool helps in this particular issue.

However, MCDM in real world systems is very often human subjective preferences or incomplete information. Grey relational analysis (GRA) is superior in theoretical analysis of systems with incomplete information (Tseng *et al*., 2008; Tseng, 2010b). This study summarizes the principles of the theories and its modeling schemes in prediction and diagnosis, and reviews its practical applications. Hence, people often employ natural language to express thinking and subjective perception; and in these natural languages the meaning of words is often vague. The meaning of a word might be well defined, when using the word as a label for a set, the boundaries with which objects do or do not belong to the set become uncertainty (Tseng, 2009). Hence, the proposed method is using GRA to appropriately express the determination of human judgment in the proposed criteria. The second contribution consists in developing a newapproach to GSCM criteria in optimal alternative.

The objective is to integrate the GSCM criteria and select an optimal alternative in an effort to catch the linguistic preferences and incomplete information in the proposed model. This study first introduces literature reviews of firm's GSCM practices implementation in section 2. The methodology used to develop and validate the firm's GSCM criteria that satisfy the content validity will be presented in section 3. Section 4 will present results of this study, followed by discussions and implications of these results in section 5. Section 6 concludes our discussion by summarizing the findings, implications, limitations, and potential topics for future research.

2. PROPOSED GSCM CRITERIA

The outcomes of literature review are integrated together with the inputs from industry and academia to compose the proposed criteria. These are the GSCM requirements for an optimal supplier. The discussion and literature reviews deliberately brought the criteria number to 18.

In the current business environment, GSCM has become critical in establishing value-added contents in a firm to ensure the profitability of supplier (C2) which is an important part of their supplier chain practices (Yao *et al*., 2007). The delivery reliability (C1) is the ability to meet delivery schedule or promises, and it is critical to react quickly to customer orders to enhance on its customer service. Moreover, the product conformance quality (C5) is a critical competitiveness which is to satisfy customer needs. To find the fitness model Tan *et al*. (1998) explored the relationships between supplier management, customer relations practices and organizational performance, used purchasing, quality and customer relations and relationship supplier closeness (C3). Sarkis (1998) categorized environmentally conscious business practices into five major components: design for the environment (green design, C8), life cycle analysis, total quality environmental management and environment related certificates such as ISO 14000 (C11).

Researchers have described it into strategic, internal green production plan (C12), cleaner production (C14), internal service quality (C7) and address the supply's purchasing perspective to improve firm's competitiveness. Carr and Smeltzer (1999) have documented how firms with strategic purchasing are able to foster long-term, cooperative relationships and communication, and achieve greater responsiveness to the needs of their suppliers. Zhu and Geng (2001) studied the firms in China and examined their environmental developments such as green purchasing (C9) in their business practices. Among the supplier selection models being used, environmentally preferable bidding and life cycle assessment (C10), which assesses green purchasing impacts and their financial consequences through the entire product life-cycle, are the most popular in the firms. However, flexibility of supplier (C6) is also a complex and multi-dimensional capability that requires a firm-wide effort to increase a firm's responsiveness and reduce waste and environmental impact. Chen *et al*. (2006) identified many quantitative and qualitative factors such as quality, price, and flexibility and delivery performance must be considered to determine the most suitable suppliers. Humphreys *et al*. (2003) identified the environmental criteria which influence a firm's management support (C13), a knowledge-based environmental management system requirements (C16) was developed next to integrate the environmental criteria to support their supplier selection process. Tseng (2010a, 2010b) presented a perception approach to deal with supplier evaluation of environmental knowledge management capacities with uncertainty. Especially, the R&D capability helps a firm expand its existing technologies and improve green R&D function. The R&D capability comprises number of patents (C17, last 3 years average), degree of innovativeness of R&D green products (C18, last 3 years average); these criteria are measured in quantitatively (Tseng *et al*., 2008; Tseng, 2010a). Hence, this study uses 18 criteria in qualitative and quantitative scales to evaluate the suitable suppliers. Figure 1 presented the conceptual framework of this study.

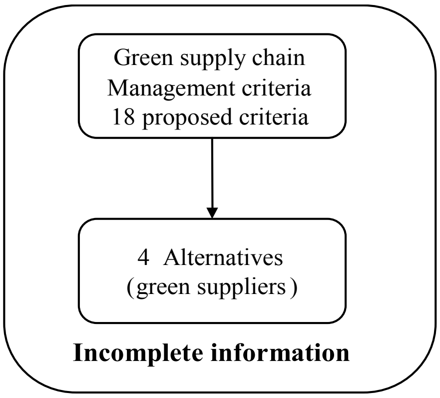

Figure 1. Conceptual framework.

3. RESEARCH METHOD

The GSCM as a strategic and decision-making perspective improves firm's present performance (Tseng *et al*., 2008). This study discusses the hybrid method as well as their associations below. The GRA definitionsand the procedures of the proposed approach are also briefly described below.

3.1 Transform the Quantitative Data

The quantitative (crisp) numbers of criteria have varying value that cannot be compared. The crisp value number must be normalized. The crisp number is normalized to achieve criteria values that are unit-free and comparable among all criteria. The normalized crisp values of W_{ij} are calculated as expressed in the following Eq. (Tseng *et al*., 2009b).

$$W_{ij}^{crisp} = \frac{W_{ij}^k - \min W_{ij}^k}{\max W_{ij}^k - \min W_{ij}^k},\ W_{ij}^{crisp} \in [0, 1];\ k = 1, 2, \cdots, n \quad (1)$$

where $\max W_{ij}^k = \max\left\{W_{ij}^1, W_{ij}^2, \cdots, W_{ij}^n\right\}$ and $\min W_{ij}^k = \min\left\{W_{ij}^1, W_{ij}^2, \cdots, W_{ij}^n\right\}$

3.2 Grey Relational Analysis

When the units in which alternative is measured are different for different criteria, the influence of some criteria may be neglected. This may also happen if some performance criteria have a very large range. In addition, if the goals and directions of these criteria are different, it will cause incorrect results in the analysis process. Therefore, processing all performance values for every alternative into a comparability sequence is necessary in a process analogous to normalization, For an MCDM problem, if there are *m* alternatives and *n* criteria, the i_{th} alternative can be expressed as $Y_i = (y_{i1}, y_{i2}, \cdots, y_{ij}, \cdots, y_{in})$, where y_{ij} is the performance value of criteria j of alternative i. The term Y_i can be translated into the comparability sequence $X_i = (x_{i1}, x_{i2}, \cdots, x_{ij}, \cdots, x_{in})$.

$$X_{ij} = \frac{y_{ij}}{Max\left\{y_{ij}, i = 1, 2, \cdots, m\right\}} \quad (2)$$
$$for\ i = 1, 2, \cdots, m \quad j = 1, 2, \cdots, n$$

All performance values will be scaled into [0, 1]. For criteria j of criteria I, if the value x_{ij} which has been processed by grey relational generating procedure, is equal to 1, or nearer to 1 than the value for any other alternative, that means the performance of alternative I is the best one for the criteria j. Therefore, an alternative will be the best choice if all of its performance values are closest to or equal to 1. However, this kind of alternative does not usually exist. This study then defines the reference sequence X_0 as $(x_{01}, x_{02}, \cdots, x_{0j}, \cdots, x_{0n}) = (1, 1, \cdots, 1, \cdots, 1)$, and then aims to find the alternative whose comparability sequence is the closest to the reference sequence.

For each criterion, the total pair comparison matrix derives from the defuzzification. However, GRA coefficient is used for determining how close x_{ij} is to x_{0j}. The larger GRA coefficient, the closer x_{ij} and x_{0j} are presented. The GRA coefficient can be calculated.

$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{ij} + \zeta\Delta_{\max}} \quad (3)$$
$$\text{for}\quad i = 1, 2, \cdots, m \quad j = 1, 2, \cdots, n$$

In Eq. (3), $\gamma(x_{0j}, x_{ij})$ is the GRA coefficient between x_{ij} and x_{0j}, and

$$\Delta_{ij} = \left|x_{0j} - x_{ij}\right|, \quad (4)$$
$$\Delta_{\min} = Min\{\Delta_{ij},\ i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n\},$$
$$\Delta_{\max} = Max\{\Delta_{ij}, i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n\},$$
$$\zeta \text{ is the distinguishing coefficient, } \zeta \in [0, 1]$$

Deng (1989) stated that the value of 0.5 is normally applied. After calculating the entire grey relational coefficient $\gamma(x_{0j}, x_{ij})$, the grey relational grade can be then calculated.

$$\gamma(x_0, x_i) = \sum_{j=1}^{n} \beta_j \gamma(x_{0j}, x_{ij}) \quad for\ i = 1, 2, \cdots, m \quad (5)$$

Here, β_j denotes the normalized weight of criterion j where $\sum_{j=1}^{n}\beta_j = 1$ and with equal weights. The proposed methodology that applies GRA to select the best supplier with respect to the GSCM is developed. The rank-ordering algorithm can be applied to find out the ranking order. The interactions of criteria are considered in this study.

4. RESULTS

This section aims to operationalize the proposed evaluation method of the GSCM to the case firm. First, the case firm continues to improve its manufacturing processes and faces the challenges to manage the environmental management and SCM. Second, the case firm has to follow the criteria in the environmental regulations in order to deal with the green criteria in supplier selection. The expert team is formed with two professors, two vice-presidents and six management professions with extensive experience related to this study.

4.1 Case Information

Printed circuit board (PCB) firm is continuing to develop new generation technology, enhance competitiveness and fully satisfy the customer demands, and develops green products to comply with customer requirements because electronic product are replaced rapidly and new green technologies and products are explored. Hence, the chief executive officer is thinking to understand the significant role of GSCM, especially the emphasis on green market. Therefore, the researchers presented this assessment to the expert group to develop the GSCM criteria. This study would provide firm's recommendations, and would be useful in the efficient and effective implementation.

4.2 Empirical Result

This study follows the five proposed steps to analyze the data from the experts. The data analysis and the results are addressed in this section. There are four A_i = (i = 1, 2, 3, 4) selection alternatives against 18 criteria Cj (j = 1, 2, 3, ⋯, 18), as detailed in Figure 1. The expert group followed the application solution in a five-phase procedure. The phases are described below:

1) The relevant empirical information was identified and gathered to ensure that the objective was achievable and that the qualitative and quantitative measures are able to merge together. It was necessary to form an expert committee with knowledge of GSCM to achieve the objectives.
2) A set of measures for the case firm evaluation was established based on consultation with a group of experts whose role was to anticipate the influence of each measure, using Eq. (1) to transform the quantitative data into compatible numbers.
3) Criteria compatibility ($\tilde{T}$) was prepared from multi-alternatives and criteria and grey relational generating-the four suppliers (A, B, C, D) for GRA input table. The main purpose of grey relational generating is transferring the original data into comparability sequences. The proposed criteria are closer-to-desired-value-the better using Eq. (2). For example, in the case of the C1 criteria, the maximum value is 0.65 from Alternative 3 and the minimum value is 0.48 from Alternative 4. Using Eqs. (3) and (4) the results of grey relational generating of supplier A are equal to 0.48/0.65 = 0.738.
4) Derivation of reference sequences, the entire GRA coefficient can be calculated by Eq. (5) and calculation of grey relational coefficient; and the optimal supplier from the grey relational grade is determined. X_0 is reference sequence. After calculating Δ_{ij}, Δ_{max} and Δ_{min}, all grey relational coefficients can be calculated. For example, $\Delta C1 = |1\text{-}0.738| = 0.262$, Δ_{max} = 1 and Δ_{min} = 0.16, if ζ = 0.5, then $\gamma(x_{0j}, x_{ij})$ = (0+0.5 ×1)/(0.262+0.5×1) = 0.656.

Hence, the importance of all GSCM criteria was assumed to be equal. Thus the weights of the 18 criteria were all the same (1/18). Using Eq. (5), the grey relational grade and ranking results can be calculated. This shows that the rank of the case firm's alternative 3 is the first priority. The proposed GRA procedure suggests that the alternative 3 is the optimal alternative (GRA coefficient = 0.765). The next alternative is alternative 4 due to the GRA coefficient (0.665) is ranked. However, the firm is in a situation in which they need to pick a single alternative as their optimal supplier prior to GSCM. Moreover, the management would like to know which criteria is concerned with the case firm most. The results indicate that the criteria ranking are C16 > C3 > C2 > C17 > C15 > C1 > C18 > C7 > C4 > C12 > C13 > C10 > C9 > C11 > C5 > C6 > C8 > C14. Although an optimal solution may not exist, due to the MCDM nature of the proposed problem, the proposed method leads to the choice of alternative as a possible final supplier. The systematic evaluation of the MCDM problem can reduce the risk of a poor choice.

5. CONCLUDING REMARKS

This study focused on developing quantitative evaluates under incomplete information using GRA. As a consequence of express representation of linguistic preference in model formulation, this reflects these uncertainties. Ultimately, the proposed 16 criteria must be considered and evaluated simultaneously. These criteria are composed of qualitative and quantitative scales. However, the qualitative data is typically inaccurate or uncertain, and the quantitative data needs to be transforming into the comparable scale. The proposed technique was used to evaluate GSCM with qualitative and quantitative expression. The hierarchical model enables an evaluator to utilize quantitative method with inherent imprecision in weighting criteria in relation to qualitative criteria by transforming linguistic expressions into crisp values. However, in real GSCM and grey relations evaluation problem, the information is not always assumed complete, and a vast amount of criteria are typically with incomplete information. The proposed model incorporates a hierarchical structure which comprises an effective method for weighting of candidate criteria from incomplete information. This method is also useful for evaluating final aggregate performance of case firm.

The contribution is first to combine the environmental and none environment criteria of SCM, two concepts into a single study framework to evaluate weighted supplier successfully, few of which can systematically evaluate the model containing of incomplete information. Furthermore, the electronic firms can apply this approach to evaluate and determine the criteria weights and to reduce the management risks. In conclusion, this study contributes, in particular, to the literatures by: 1) proposing a GSCM hierarchical framework that composes environmental and none environment criteria of SCM in a framework; 2) developing valid and reliable measures for the GSCM based on expert's qualitative preferences together with quantitative data, and 3) developing a hybrid method to solve while evaluation is using linguistic preferences together with quantitative data and incomplete information.

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