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Green supply chain management in the electronic industry

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ABSTRACT: Green supply chain management has emerged as a proactive approach for improving environmental performance of processes and products in accordance with the requirements of environmental regulations. Various approaches for implementing green supply chain management practices has been proposed and recognized in previous literatures, yet no investigation has identified the reliability and validity of such approaches particularly in electronic industry. This study examines the consistency approaches by factor analysis that determines the adoption and implementation of green supply chain management in Taiwanese electronic industry. The fuzzy analytic hierarchy process method is applied to prioritize the relative importance of four dimensions and twenty approaches among nine enterprises in electronic industry. The findings indicate that these enterprises would emphasize on supplier management performance in the crucial role of implementing green supply chain management. Establishing an environmental database of products, asking for product testing report and top management support are among the most important approaches. The results for the implications of green supply chain management implementation in electronic industry investigated in this work generate a generic hierarchy model for decision-makers who can prioritize those approaches for implementing green supply chain management in Taiwan.

Key words: *Priority approaches, fuzzy analytic hierarchy process, supply chain environmental management*

INTRODUCTION

With increase in environmental concerns during the past decade, a consensus is growing that environmental pollution issues accompanying industrial development should be addressed together with supply chain management, thereby contributing to green supply chain management (GSCM) (Sheu *et al.*, 2005). Since the Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS) and Eco-design for Energy using Products (EuP) directives were passed by the European Union (EU), GSCM has been adopted as a proactive strategy by leading electronic industry companies, including Dell, HP, IBM, Motorola, Sony, Panasonic, NEC, Fujitsu and Toshiba (Zhu and Sarkis, 2006). Nowadays, similar regulation has been spread throughout the world in the US, China, Japan and Korea; the emerging issue of green product seems to be quickly picked up in Asia. Some countries such Japan, Taiwan and Korea are the heralds in terms of green electronic products (Boysère and Beard, 2006). Thus, it is inferred that GSCM practice can be viewed as the primary strategy capable of complying with the requirements of legislations and maintaining the competitive advantage. The issue of GSCM is significant for Taiwan's electronics industry as recent studies have shown that most of the world's manufacturing will be relocated to Asia within the next two decades (US-AEP, 1999). Therefore, GSCM is an operational initiative on the part of many organizations, including those in Asia and South Asian region which are adopting to address such environmental issues (Rao and Holt, 2005). Taiwan is one of the most industrialized countries in the Asia-Pacific region. Most electrical and electronics manufacturers in Taiwan are involved in Original Equipment Manufacturing (OEM) and Original Design Manufacturing (ODM). These companies play important roles in global markets as their products share a substantial portion in market. Once, Taiwan was the third largest producer of information products all round the world (Chen, 2004). Nevertheless, these industries are subject to customer requests for green products and green manufacturing that comply with emerging environmental directives (such as WEEE, RoHS and EuP). These directives, especially the RoHS, directly impact the electrical and electronics industries in Taiwan and export products to the EU-exports in 2004 exceeded US$7.8 billion. More

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than 3,000 companies were affected by the directives of the EU. These directives also have a far-reaching influence on supply chain partners for multinational enterprises (Huang, 2005). Although, to the best of our knowledge, various investigations have proposed different approaches to implement GSCM (Lamming and Hampson, 1996; Lippmann, 1999; US-AEP, 1999; Bowen *et al.,* 2001; Yuang and Kielkiewicz-Yuang, 2001; Rao, 2002; Evans and Johnson, 2005; Zhu *et al.,* 2005), there have been far less research on identifying the consistency and priority approaches to GSCM implementation with the systematic analysis, particularly in electronics industry. This is because the complexity of GSCM practices, customer and cost pressures and regulation uncertainty, implementing GSCM is considered as a thankless task that increases overall product cost. For example, the RoHS directive lacks a standardized test procedure and an updated exemption annex of chemicals. These shortcomings result in significant problems when implementing GSCM. Furthermore, increased regulations - RoHS-EU, RoHS-Korea and RoHS-China - result in difficulties executing GSCM practices. Hence, enterprises cannot determine whether their executive strategies conform to regulations or ensure that current management approaches are working and have a low risk. Consequently, enterprise embraces the appropriate approaches for implementing GSCM practice and it is significant to mitigate potential risks from green supply chain. The central purpose of this study is to establish the consistency and priority approaches for implementing GSCM in response to environmental regulations of WEEE, RoHS and EuP. The fuzzy analytic hierarchy process (FAHP), which is applied to conduct the relative importance of different approaches, is extremely crucial, since the results can be used by managers implementing and adopting their own GSCM practices.

MATERIAL AND METHODS

To improve the AHP method and to recognize consistent strategies for implementing GSCM, this study applies the FAHP and uses triangular fuzzy numbers to express comparative judgments of decision-makers. A systematic approach of FAHP to identify priority approaches for GSCM implementation was adopted based on a complex and multi-criteria environment. From September to November 2006, the authors utilized FAHP to recognize the priority approaches that will affect the implementation of GSCM practice in Taiwanese electronics industry. The methodology consists of three phases, including (1) constructing the hierarchy of GSCM practice via factor analysis, (2) collecting data from industrial expert interviews and (3) determining the normalized weights of individual dimensions and approaches. The GSCM practices implementation and FAHP will be discussed through a literature review and the construction of the hierarchy of GSCM implementation will also be presented afterwards.

Approaches to GSCM implementation

A number of approaches for implementing GSCM practice have been proposed in previous literature, in which they are aimed at mitigating the risks associated with green supply chain interruptions or delays and protecting a company's reputation and brand image from damaging public controversies. Various approaches to GSCM practice have been identified by various researches; they are briefly outlined below and summarized as shown in Table 1. Lamming and Hampson (1996) explored the concepts of environmentally sound management (e.g. life cycle analysis, waste management, product stewardship and the like) and linked them to supply chain management practices such as vendor assessment, lean supply, collaborative supply strategies, establishing environmental purchasing policy and working with suppliers to enable improvements. Lippmann (1999) proposed various critical elements for the successful implementation of supply chain environmental management. Those components include the production of written GSCM policies, supplier meetings, training, collaborative R&D, top-level leadership, cross-functional integration, effective communication within companies and with suppliers, effective processes for targeting, evaluating, selecting and working with suppliers and restructuring relationships with suppliers and customers.

US-AEP (1999) improved understanding of industry approaches to supply chain environmental management (SCEM) by focusing on seven major electronics firms. Some of the common SCEM tools employed by these firms are summarized as follows:

- Prequalification of suppliers
- Environmental requirements during the purchasing phase
- Supply base environmental performance management

Table 1: Approaches for GSCM implementation emphasized by selected authors

Approach	Representative references
1. Suppliers meeting	Lippmann (1999), Yuang and Kielkiewicz–Yuang (2001), Rao (2002)
2. Environmental auditing for suppliers	Lippmann (1999), US-AEP (1999), Yuang and Kielkiewicz–Yuang (2001), Zhu *et al.* (2005)
3. Suppliers environmental questionnaire	Lamming and Hampson (1996), US-AEP (1999), Bowen *et al.* (2001), Rao (2002), Evans and Johnson (2005)
4. Requesting compliance statement	Yuang and Kielkiewicz–Yuang (2001), Evans and Johnson (2005)
5. Asking for product testing report	Evans and Johnson (2005)
6. Demanding bill of material (BOM)	Evans and Johnson (2005)
7. Establishing environmental requirements for purchasing items	Lamming and Hampson (1996), Lippmann (1999), US-AEP (1999), Evans and Johnson (2005)
8. Implementing green purchasing	Yuang and Kielkiewicz–Yuang (2001), Rao (2002), Zhu *et al.* (2005)
9. Collaborative R&D with suppliers	Lamming and Hampson (1996), Lippmann (1999), US-AEP (1999), Bowen *et al.* (2001), Rao (2002)
10. Information system	Yuang and Kielkiewicz–Yuang (2001), Evans and Johnson (2005)
11. Joining local recycling organizations	US-AEP (1999), Bowen *et al.* (2001), Rao (2002)
12. Collaboration on products recycling with the same sector industry	Yuang and Kielkiewicz–Yuang (2001)
13. Produce disassembly manuals	Lamming and Hampson (1996), Rao (2002)
14. Green design	US-AEP (1999), Yuang and Kielkiewicz–Yuang (2001), Rao (2002)
15. Environmental education and training	Lippmann (1999), Yuang and Kielkiewicz–Yuang (2001)
16. Top management support	Lippmann (1999), US-AEP (1999), Evans and Johnson (2005)
17. Environmental policy for GSCM	Lamming and Hampson (1996), Lippmann (1999), US-AEP (1999), Yuang and Kielkiewicz–Yuang (2001)
18. Cross-function integration	Lippmann (1999), US-AEP (1999), Yuang and Kielkiewicz–Yuang (2001), Evans and Johnson (2005)
19. Manpower involvement	Rao (2002)
20. Effective communication platform within companies and with suppliers	Lippmann (1999)
21. Establish a environmental risk management system for GSCM	Bowen *et al.* (2001)
22. Supplier evaluation and selection	Lamming and Hampson (1996), Yuang and Kielkiewicz–Yuang (2001), Rao (2002)
23. Tracking the development of directives	US-AEP (1999)
24. Applying LCA to carry out eco-report	Lamming and Hampson (1996), US-AEP (1999), Rao (2002)
25. Establish an environmental database of products	Lamming and Hampson (1996)

- Building environmental considerations into product design
- Cooperating with suppliers to deal with end-of-pipe consumer environmental issues
- Reverse logistics
- Influencing legislation to facilitate better SCEM policies
- Working with industry peers to standardize requirements (for suppliers and purchasing items)
- Informing suppliers of corporate environmental concerns
- Promoting the exchange of information and ideas

Bowen *et al.* (2001) conducted an exploratory analysis of implementing patterns and inductively derived three main types of green supply. The first type, i.e. greening the supply process, represents adaptations to supplier management activities, including collaboration with suppliers to eliminate packaging and recycling initiatives. The second type, i.e. product-based green supply, attempts to manage the by-products of supplied inputs such as packing. The third type, i.e. advanced green supply, includes more proactive approaches such as the use of environmental criteria in risk-sharing, evaluation of buyer performance and joint clean technology programs with suppliers. Yuang and Kielkiewicz-Yuang (2001) presented an overview of current practices in managing sustainability issues in supply networks. Cross-functional teams, consisting of sales, environmental personnel, purchasing personnel and personnel from other relevant departments, can be found in organizations with the most advanced strategies for sharing sustainability-oriented information. Organizations make available to their customers/ suppliers their sustainability purchasing policy, goals and future targets via open days. Moreover, organizations have specific criteria as well as recognized standards (ISO14001), technical (lead-free soldering) and performance specifications that its suppliers must meet to be recognized as preferred suppliers. In addition, supplier performances can be enhanced through on-site third-party auditing or periodic self-assessment by suppliers. Through collaboration with suppliers, training not only is administered to companies that provide advice on sustainability issues in purchasing, but also is delivered to suppliers to provide them with information on product life cycle. Rao (2002) argues that GSCM practices should include working collaboratively with suppliers on green product designs, holding awareness seminars, helping suppliers establish their own environmental programs and so on. To green the supply chain, from the perspective of practitioners, companies have to integrate the ideas of green purchasing total quality management in terms of employee empowerment, customer focus, continuous improvement and zero waste, life cycle analysis and environmental marketing. Green purchasing comprises a number of environment-based initiatives, including a supplier environmental questionnaire, supplier environmental audit and assessments, environmental criteria for designating approved suppliers, requiring suppliers to undertake independent environmental certification, jointly developing cleaner technology/ processes with suppliers, engaging suppliers in eco-design and product/ process innovation. Evans and Johnson (2005) suggested that manufacturers should install documented and auditable systems to prevent non-compliant products from entering the EU. The installation of such systems would involve three steps. The first step is to determine the legal exposure of the company to the EU directives and senior management must support this initial exposure assessment. The next step is to assign the task to a corporate-wide compliance team due to the complex requirements of the RoHS directive. The third step is to develop a corporate compliance statement, which should include a date for compliance and might also outline supplier requirements, i.e. testing, documentation and so on. Through assessing the supply chain exposure to the EU directives, companies can establish the material declaration process. However, companies should also qualify suppliers to determine their level of RoHS preparedness via questionnaires. Zhu *et al.* (2005) described a number of GSCM practices implemented by Chinese enterprises to improve their performance. Internal environmental management is a key to improving enterprise performance in terms of senior manager commitment and cross-functional cooperation. Commitment of senior managers is extremely conducive to the implementation and adoption stages for GSCM, because without such upper management commitment most programs are bound to fail. All GSCM practices are integrative and require cross-functional cooperation rather than simply being oriented to a single function or department. They suggested that green purchasing and eco-design are two emerging approaches and companies should focus on the inbound or early portions of the product supply chain. Currently, large customers have exerted pressure on their suppliers to achieve better environmental performance, resulting in greater motivation for suppliers to cooperate with customers for environmental objectives.

Fuzzy analytic hierarchy process

The analytical hierarchy process (AHP) method, introduced by Saaty (1980), directs how to determine the priority of a set of alternatives and the relative importance of attributes in a multi-criteria decision-making (MCDM) problem (Saaty, 1980; Wei *et al.,* 2005). The primary advantage of the AHP approach is the relative ease with which it handles multiple criteria and performs qualitative and quantitative data (Kahraman *et al.,* 2004; Meade and Sarkis, 1998). However, AHP is frequently criticized for its inability to adequately accommodate the inherent uncertainty and imprecision associated with mapping decision-maker perceptions to extract number (Kwong and Bai, 2003; Chan and Kumar, 2007). It is difficult to response to the preference of decision-makers by assigning precise numerical values. The FAHP, therefore, was applied to determine weight among various approaches for implementing GSCM and provided the priority of those approaches for enterprise to adopt and adjust their current GSCM practices. Some calculation steps are essential and explained as follows:

Step 1: Establishing the hierarchical structure

Constructing the hierarchical structure with decision elements, decision-makers are requested to make pair-wise comparisons between decision alternatives and criteria using a nine-point scale. All matrices are developed and all pair-wise comparisons are obtained from each *n* decision-maker(s).

Step 2: Calculating the consistency

To ensure that the priority of elements is consistent, the maximum eigenvector or relative weights and $\lambda_{\max}$ is calculated. Then, the consistency index (CI) for each matrix order *n* is computed by using Eq. (1). Based on the CI and random index (RI), the consistency ratio (CR) is calculated using Eq. (2). The CI and CR are defined as follows (Saaty, 1980):

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \quad (1)$$

$$C.R. = \frac{C.I.}{R.I.} \quad (2)$$

where, *n* is the number of items being compared in the matrix, $\lambda_{\max}$ is the largest eigenvalue and RI is a random consistency index obtained from a large number of simulation runs and varies upon the order of matrix (see Table 2).

Step 3: Constructing a fuzzy positive matrix

A decision-maker transforms the score of pair-wise comparison into linguistic variables via the positive triangular fuzzy number (PTFN). The fuzzy positive reciprocal matrix can be defined as (Buckley, 1985)

$$\tilde{A}^k = \left[\tilde{A}_{ij}{}^k\right] \quad (3)$$

where, $\tilde{A}^k$ is a fuzzy position reciprocal matrix of decision-maker *k*; $\tilde{A}_{ij}{}^k$ is the relative importance between *i* and *j* of decision elements $\tilde{A}_{ij}{}^k = 1, \quad \forall i = j, \quad \tilde{A}_{ij}{}^k = 1/A_{ij}{}^k, \quad \forall i, j = 1,2,.....,n$

Step 4: Calculating fuzzy weights value

According to the Lambda-Max method proposed by Csutora and Buckley (2001), the fuzzy weights of the hierarchy can be calculated. This process is described as follows:

- Let á=1 to obtain the positive matrix of decision-maker $\tilde{A}_m^k = [a_{ijm}]_{n\,x\,n}$. Then, apply the AHP to calculate weight matrix W_m^k.

$$W_m^k = \left[w_{im}^k\right], \ i = 1, 2, ..., n \quad (4)$$

- Let α=0 to obtain the lower bound and upper bound of the positive matrix of decision-maker, $\tilde{A}_l^k = [a_{ijl}]_{n\,x\,n}$ and $\tilde{A}_u^k = [a_{iju}]_{n\,x\,n}$. Then, apply the AHP to calculate the weight matrix: W_l^k and W_u^k.

Table 2: Random index

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

$$W_l^k = \left[w_{il}^k \right],\ i = 1, 2, \ldots\ldots, n \quad (5)$$

$$W_u^k = \left[w_{iu}^k \right],\ i = 1, 2, \ldots\ldots, n \quad (6)$$

• To ensure the fuzziness of weight, two constants, i.e. S_l^k and S_u^k, are calculated as follows:

$$S_l^k = \min\left\{ \frac{w_{im}^k}{w_{il}^k} \middle| 1 \le i \le n \right\} \quad (7)$$

$$S_u^k = \min\left\{ \frac{w_{im}^k}{w_{iu}^k} \middle| 1 \le i \le n \right\} \quad (8)$$

The lower bound ($W_l^{k^*}$) and upper bound ($W_u^{k^*}$) of the weight matrix are defined as:

$$W_l^{k^*} = \left[w_{il}^{k^*} \right],\quad w_{il}^{k^*} = S_l^k w_{il}^k,\ i = 1, 2, \ldots, n \quad (9)$$

$$W_u^{k^*} = \left[w_{iu}^{k^*} \right],\quad w_{iu}^{k^*} = S_u^k w_{iu}^k,\ i = 1, 2, \ldots, n \quad (10)$$

• Aggregating $W_l^{k^*}$, $W_m^{k^*}$ and $W_u^{k^*}$, the fuzzy weight for decision-maker k can be acquired as follows:

$$\tilde{W}_i^k = \left(w_{il}^{k^*},\ w_{im}^{k^*}, w_{iu}^{k^*} \right),\quad i = 1, 2, \ldots, n \quad (11)$$

• Applying the geometric average to incorporate the opinions of decision-makers is defined as follows:

$$\tilde{\tilde{W}}_i = 1/k \left(\tilde{W}_i^1 \otimes \tilde{W}_i^2 \otimes \ldots\ldots\ldots \otimes \tilde{W}_i^n \right) \quad (12)$$

where,

$\tilde{\tilde{W}}_i$: the fuzzy weight of decision-makers i is incorporated with K decision-makers.

$\tilde{W}_i^k$: the fuzzy weight of decision element i of k decision-maker.

k: number of decision-makers.

Constructing the hierarchy of GSCM practice via factor analysis

Through a thorough and detailed analysis of the pertinent literature and in-depth interviews with three senior quality assurance and product assurance representatives, a tentative list of 25 approaches of GSCM was developed as the basis for questionnaire development. Respondents were asked to rate each item under a five-point Likert-type scale (e.g. 1 = not at all important, 2 = not important, 3 = moderate, 4 = important, 5 = extremely important) to indicate the extent to which each item was practiced in their respective organization. This investigation focused on sampling the perceptions and experiences of GSCM-based companies in the Taiwanese electrical and electronics industries. Data collection involved distributing questionnaires involved in electronic enterprises. Target respondents were selected from among the members of Taiwan Electrical and Electronics Manufacturers Association (TEEMA). Questionnaires were addressed to both the managing directors of the quality assurance and purchasing departments of the target organizations. This was done because most of the sample companies may lack GSCM representatives or departments. A total of 300 questionnaires were mailed out and 87 were returned, of which 84 were valid, representing a response rate of 28%. According to the study on development and validation of critical factors and environmental management, its response rate is 21.9% (Wee and Quazi, 2005). Furthermore, Antony *et al.* (2002) also pointed out that their research got 16.5%, which was normal and reasonable. This implies that the response rate of this study is acceptable and it reflects the virtue of novel issue of the GSCM practice. The authors utilized factor analysis to extract factors based upon the principal components analysis with varimax rotation. Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy were employed to test the appropriateness of the data for factor analysis (Kaiser, 1974; Bagozzi and Yi, 1998). The test results of KMO show that the compared value is 0.863, significantly exceeding the suggested minimum standard of 0.5 required for conducting factor analysis (Hair *et al.,* 1995). The authors performed factor analysis to extract factors in accordance with the eigenvalues of discontinuity which is greater than 1 (Tabachnick and Fidell, 1989) and factor loading exceeding 0.6 were necessary to choose factors (Kline, 1997). These are five variables eliminated

Table 3: Triangular fuzzy numbers (Lee *et al.*, 2008)

Linguistic variables	Positive triangular fuzzy number	Positive reciprocal triangular fuzzy number
Extremely strong	(9, 9, 9)	(1/9, 1/9, 1/9)
Intermediate	(7, 8, 9)	(1/9, 1/8, 1/7)
Very strong	(6, 7, 8)	(1/8, 1/7, 1/6)
Intermediate	(5, 6, 7)	(1/7, 1/6, 1/5)
Strong	(4, 5, 6)	(1/6, 1/5, 1/4)
Intermediate	(3, 4, 5)	(1/5, 1/4, 1/3)
Moderately strong	(2, 3, 4)	(1/4, 1/3, 1/2)
Intermediate	(1, 2, 3)	(1/3, 1/2, 1)
Equally strong	(1, 1, 1)	(1, 1, 1)

tests and item analysis were recalculated without those five items. Table 4 lists the Cronbach's alpha values, ranging from 0.8338 to 0.9367, after the five items were dropped. Generally, Cronbach's alpha value exceeding 0.7 is considered to have high internal consistency of scale (Lin *et al.*, 2002). All the Cronbach's alpha values in our study are greater than 0.7, revealing the high internal consistency. Content validity depends on how well the researchers create measurement items to cover the content domain of the variable measured (Nunnally,

Table 4: Factor analysis results

Dimension	Approaches	Item loading range	Eigenvalues	Cumulative percentage	Cronbach's alpha
Supplier management (D_1)	1. Environmental auditing for suppliers (D_{11}) 2. Supplier environmental questionnaire (D_{12}) 3. Requesting compliance statement (D_{13}) 4. Asking for product testing report (D_{14}) 5. Demanding bill of material (BOM) (D_{15}) 6. Establishing environmental requirements for purchasing items (D_{16}) 7. Implementing green purchasing (D_{17})	0.657 0.722 0.828 0.842 0.619 0.747 0.830	12.504	50.02	0.9289
Product recycling (D_2)	1. Joining local recycling organization (D_{21}) 2. Collaboration on products recycling with the same sector industry (D_{22}) 3. Produce disassembly manual (D_{23})	0.886 0.931 0.613	2.605	60.44	0.8338
Organization involvement (D_3)	1. Green design (D_{31}) 2. Top management support (D_{32}) 3. Environmental policy for GSCM (D_{33}) 4. Cross-function integration (D_{34}) 5. Manpower involvement (D_{35}) 6. Effective communication platform within companies and with suppliers (D_{36}) 7. Establish an environmental risk management system for GSCM (D_{37}) 8. Supplier evaluation and selection (D_{38})	0.624 0.618 0.658 0.750 0.769 0.677 0.727 0.639	1.325	65.74	0.9367
Life cycle management (D_4)	1. Applying LCA to carry out eco-report (D_{41}) 2. Establish an environmental database of products (D_{42})	0.830 0.829	1.032	69.87	0.9156

because their factor loadings are less than 0.06. The remaining 20 items, therefore, were re-analyzed and extracted into four dimensions, which was denominated as supplier management, product recycling, organization involvement and life cycle management as a hierarchy of the GSCM implementation (See Fig. 1). Reliability concerns the extent to which an experience, test or any measuring procedure yields the same results on repeated trials (Carmines and Zeller, 1979). The reliability of the factors needs to be determined to support any measures of validity that may be employed (Nunnally, 1978). Internal consistency analysis was performed to measure the reliability of the items under each critical factor using Cronbach's alpha (Wee and Quazi, 2005). Both reliability

1967). Content validity is subjectively evaluated by researchers (Yusof and Aspinwall, 2000). The content validity of the questionnaire in this work is based on an exhaustive literature review and detailed evaluations by three senior quality assurance and product assurance practitioners. Consequently, the measures of GSCM constructed by the factor analysis have content validity. Criterion-relation validity, sometimes called predictive validity or external validity, is concerned with the extent to which a measuring instrument is related to an independent measure of the relevant criterion (Badri and Davis, 1995). No criterions were designed to explore the correlation with the performance of GSCM. The results of this study may provide a better understanding and help identify the opportunities of GSCM implementation.

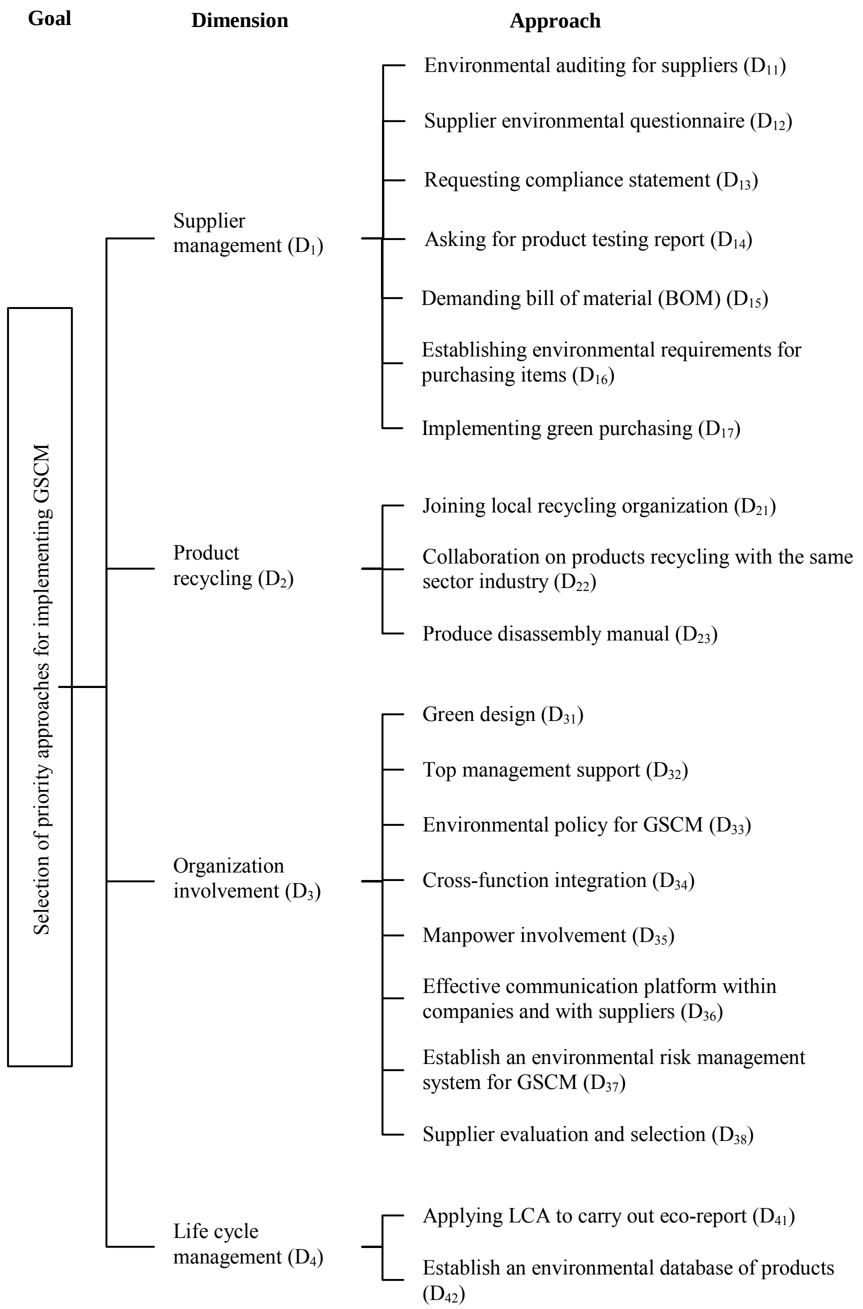

Fig.1: The hierarchy of GSCM implementation

Measuring and collecting data

Managers who are responsible for implementing GSCM of nine well-known IT enterprises from Green Plan (GP) program were invented to attend a personal interview. These companies were familiar with the GSCM practices in their organizations; they served as evaluators to determine the relative weights against a given list of approaches affecting implementation of GSCM practice. These companies were selected as the member of GP program which was launched by the Ministry of Economic Affairs (MOEA) at the end of 2004 for promoting GSCM practice in complying with EU's environmental regulations as WEEE, RoHS and

Table 5: Local and global weights of each approach for implementing GSCM

Dimension	Local weights[a]	Approach	Local weights	Global weights[b]	Ranking
Supplier management (D_1)	0.4337	Environmental auditing for suppliers (D_{11})	0.1625	0.0708	5
		Supplier environmental questionnaire (D_{12})	0.0408	0.0178	17
		Requesting compliance statement (D_{13})	0.1448	0.0630	6
		Asking for product testing report (D_{14})	0.2026	0.0882	2
		Demanding bill of material (BOM) (D_{15})	0.1917	0.0835	4
		Establishing environmental requirements for purchasing items (D_{16})	0.1178	0.0513	9
		Implementing green purchasing (D_{17})	0.1398	0.0609	7
Product recycling (D_2)	0.1161	Joining local recycling organization (D_{21})	0.3692	0.0430	13
		Collaboration on products recycling with the same sector industry (D_{22})	0.1241	0.0145	19
		Produce disassembly manual (D_{23})	0.5067	0.0591	8
Organization involvement (D_3)	0.3234	Green design (D_{31})	0.0492	0.0160	18
		Top management support (D_{32})	0.2670	0.0867	3
		Environmental policy for GSCM (D_{33})	0.1519	0.0493	10
		Cross-function integration (D_{34})	0.1461	0.0474	11
		Manpower involvement (D_{35})	0.0924	0.0300	16
		Effective communication platform within companies and with suppliers (D_{36})	0.1446	0.0469	12
		Establish an environmental risk management system for GSCM (D_{37})	0.0379	0.0123	20
		Supplier evaluation and selection (D_{38})	0.1110	0.0360	14
Life cycle management (D_4)	0.1228	Applying LCA to carry out eco-report (D_{41})	0.2500	0.0308	15
		Establish an environmental database of products (D_{42})	0.7500	0.0925	1

a. Local weight is derived from judgment with respect to a single criterion.
b. Global weight is derived from multiplication by the weight of the criteria

EUP. Many electronics companies, particularly in assembly manufacturers, are involved and embrace various green initiatives to green their supply chain, including three tasks: establishing an information management system for green supply chains; developing a recycling system and management platform for green products and generating a certification database for green parts and components (MOEA, 2005). In terms of the extracted results of factor analysis, a FAHP-based questionnaire survey was designed and delivered to nine industrial experts who have substantial experience implementing GSCM practices for collecting data out of pair-wise comparisons. A nine-point scale was occupied to assign relative importance to pair-wise comparisons among dimensions and approaches.

Determining the normalized weights

To determine the relative importance of the dimensions and approaches, a set of pair-wise comparison matrices were translated into the eigenvectors problems and then were normalized to unify the result so as to acquire the vectors of priorities. The geometric mean is utilized to aggregate the pair-wise comparisons for all samples. The normalized local and global weights of the dimensions and approaches were generated by the procedure aforementioned (see Tables 6 to 10). The results suggested that the overall consistency of respondents' judgments fall within the acceptable ratio of 0.10.

RESULTS AND DISSCUSION

Nine enterprises have participated in this study, in which all were large and medium assembly manufacturers in Taiwanese electronics industries. In order to determine the importance of the dimensions and approaches, the judgments collected from respondents generated the normalized local and global weights for approaches to implementing GSCM. The results of priority weights determined the relative importance of individual dimensions and approaches and in turn recognized the points on which organizations should put their efforts throughout the process of GSCM implementation. In addition, the results could represent the general status of GSCM implementation in Taiwanese electronics enterprises. Three sets of normalized weights had generated to determine the importance of approaches to GSCM implementation as shown in Table 5. The second column is the local weights with respect to the dimensions; the fourth and fifth columns are the local and global weights for each approach, respectively. The global weights of each approach have been calculated by multiplying the local weights of each approach by the local weights of each dimension.

Table 6: Pairwise comparison matrix and weights with respect to the goal

	D_1	D_2	D_3	D_4	Weights
D_1	(1, 1, 1)	(4.932, 5.944, 6.952)	(0.956, 1.387, 2.080)	(1.817, 2.190, 2.653)	0.4377
D_2	(0.144, 0.160, 0.203)	(1, 1, 1)	(0.454, 0.575, 0.747)	(0.630, 0.928, 1.357)	0.1161
D_3	(0.481, 0.721, 1.046)	(1.339, 1.738, 2.201)	(1, 1, 1)	(3.420, 4.481, 5.518)	0.3234
D_4	(0.377, 0.457, 0.550)	(0.737, 1.077, 1.587)	(0.181, 0.223, 0.292)	(1, 1, 1)	0.1228

λ_{max} = 4.0570 CI=0.019 CR=0.021

Table 7: Pairwise comparison matrix and weights with respect to supplier management dimension

	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}	D_{16}	D_{17}	Weights
D_{11}	(1, 1, 1)	(6.316, 7.319, 8.320)	(1.651, 2.520, 3.684)	(0.347, 0.585, 1.000)	(0.275, 0.405, 0.630)	(1.260, 1.587, 1.957)	(0.500, 0.620, 0.794)	0.1625
D_{12}	(0.120, 0.137, 0.158)	(1, 1, 1)	(0.275, 0.405, 0.630)	(0.210, 0.281, 0.397)	(0.151, 0.179, 0.218)	(0.210, 0.281, 0.397)	(0.223, 0.315, 0.457)	0.0408
D_{13}	(0.271, 0.397, 0.606)	(1.587, 2.466, 3.634)	(1, 1, 1)	(0.500, 1.000, 2.000)	(0.500, 1.000, 2.000)	(0.630, 1.260, 2.289)	(1.000, 1.817, 2.621)	0.1448
D_{14}	(1.000, 1.710, 2.884)	(2.520, 3.557, 4.762)	(0.500, 1.000, 2.000)	(1, 1, 1)	(1.260, 2.080, 3.175)	(0.794, 1.260, 2.154)	(0.909, 1.587, 2.714)	0.2026
D_{15}	(1.587, 2.466, 3.634)	(4.579, 5.593, 6.604)	(0.500, 1.000, 2.000)	(0.315, 0.481, 0.794)	(1, 1, 1)	(1.260, 2.154, 3.302)	(0.630, 1.260, 2.289)	0.1917
D_{16}	(0.511, 0.630, 0.794)	(2.520, 3.557, 4.762)	(0.437, 0.794, 1.587)	(0.464, 0.794, 1.260)	(0.303, 0.464, 0.794)	(1, 1, 1)	(0.437, 0.794, 1.587)	0.1178
D_{17}	(1.260, 1.613, 2.000)	(2.190, 3.175, 4.481)	(0.347, 0.550, 1.000)	(0.368, 0.630, 1.101)	(0.437, 0.794, 1.587)	(0.630, 1.260, 2.289)	(1, 1, 1)	0.1398

λ_{max} =7.0145 CI=0.0241 CR=0.0183

Table 8: Pairwise comparison matrix and weights with respect to product recycling dimension

	D_{21}	D_{22}	D_{23}	Weights
D_{21}	(1, 1, 1)	(2.000, 2.924, 4.160)	(0.397, 0.693, 1.260)	0.3692
D_{22}	(0.240, 0.342, 0.500)	(1, 1, 1)	(0.198, 0.251, 0.347)	0.1241
D_{23}	(0.794, 1.442, 2.520)	(2.884, 3.979, 5.040)	(1, 1, 1)	0.5067

λ_{max} =3.0042 CI=0.0021 CR=0.0036

Table 9: Pairwise comparison matrix and weights with respect to organization involvement dimension

	D_{31}	D_{32}	D_{33}	D_{34}	D_{35}	D_{36}	D_{37}	D_{38}	Weights
D_{31}	(1, 1, 1)	(0.191, 0.317, 0.347)	(0.138, 0.160, 0.191)	(0.138, 0.160, 0.191)	(0.347, 0.441, 0.550)	(0.173, 0.212, 0.275)	(0.693, 1.000, 1.442)	(0.630, 0.894, 1.260)	0.0492
D_{32}	(2.884, 3.979, 5.241)	(1, 1, 1)	(1.000, 1.442, 2.080)	(1.000, 1.442, 2.080)	(2.000, 2.621, 3.557)	(2.884, 4.160, 5.130)	(1.687, 2.080, 2.466)	(2.000, 2.621, 3.557)	0.2670
D_{33}	(5.241, 6.257, 7.268)	(0.303, 0.481, 0.794)	(1, 1, 1)	(0.693, 1.145, 2.000)	(0.794, 1.442, 2.520)	(0.437, 0.794, 1.587)	(0.500, 1.000, 2.000)	(0.693, 1.145, 2.000)	0.1519
D_{34}	(5.241, 6.257, 7.268)	(0.481, 0.693, 1.000)	(0.500, 0.874, 1.442)	(1, 1, 1)	(1.000, 1.817, 2.884)	(0.585, 0.909, 1.387)	(0.368, 0.630, 1.101)	(0.630, 1.000, 1.587)	0.1461
D_{35}	(1.817, 2.268, 2.884)	(0.281, 0.382, 0.500)	(0.397, 0.693, 1.260)	(0.347, 0.550, 1.000)	(1, 1, 1)	(0.347, 0.585, 1.000)	(0.368, 0.630, 1.101)	(0.437, 0.737, 1.145)	0.0924
D_{36}	(3.634, 4.718, 5.769)	(0.195, 0.240, 0.347)	(0.630, 1.260, 2.289)	(0.721, 1.101, 1.710)	(1.000, 1.710, 2.884)	(1, 1, 1)	(0.437, 0.737, 1.145)	(1.000, 1.817, 2.884)	0.1446
D_{37}	(0.693, 1.000, 1.442)	(0.405, 0.481, 0.593)	(0.500, 1.000, 2.000)	(0.909, 1.587, 2.714)	(0.909, 1.587, 2.714)	(0.874, 1.357, 2.289)	(1, 1, 1)	(0.550, 0.000, 0.000)	0.0379
D_{38}	(0.794, 1.119, 1.587)	(0.281, 0.382, 0.500)	(0.500, 0.874, 1.442)	(0.630, 1.000, 1.587)	(0.874, 1.357, 2.289)	(0.347, 0.550, 1.000)	(0.874, 1.357, 2.289)	(1, 1, 1)	0.1110

λ_{max} =8.1138 CI=0.0163 CR=0.0115

Incorporating the analysis of FAHP evidences, the local weights for each dimension demonstrate that ‘supplier management’ (0.4337) and ‘organizational involvement’ (0.3234) are the two most important dimensions for implementing GSCM practice, followed

Table 10: Pairwise comparison matrix and weights with respect to life cycle management dimension

	D_{41}	D_{42}	Weights
D_{41}	(1, 1, 1)	(0.232, 0.329, 0.481)	0.250
D_{42}	(2.080, 3.037, 4.309)	(1, 1, 1)	0.750

λ_{max} =2.0915 CI=0.0915 CR=0.0000 by 'life cycle management' (0.1228). 'Product recycling' (0.1161) reveals to be the dimension with the lowest importance as shown in Table 5. The approaches of 'product testing reports' (0.2026), 'produce disassembly manual' (0.5067), top management support (0.2670) and 'establish an environmental database of products' (0.7500) reveal the highest importance with regard to each dimension in sequence of supplier management, product recycling, organization involvement and life cycle management, respectively. Considering the global weights in Table 5, it is evident that the ten prioritized approaches for implementing GSCM in Taiwanese electrical and electronics industry follow this order: 'establish an environmental database of products' (0.0925), 'product testing report' (0.0882), 'top management support' (0.0867), 'bill of material (BOM)' (0.0835), 'environmental auditing for suppliers' (0.0708), 'compliance statement' (0.0630), 'green purchasing' (0.0609), 'produce disassembly manual' (0.0591), 'establishing environmental requirements for purchasing items' (0.0513) and 'environmental policy for GSCM' (0.0493). Moreover, the resulting global weights have also shown that a great majority of ten prioritized approaches was the dimension of supplier management. The findings affirmed the supplier management performs in the crucial role of implementing GSCM. In addition, the priority approaches of GSCM implementation show the respondents' perceptions about the importance of them and assisted organizations recognize their strengths to move towards continuous improvement. Recognizing the consistency and priority approaches for implementing GSCM is important because of the uncertainties in current environmental regulations so that enterprises cannot ensure whether current management approaches can comply with the requirements of regulations. Although the previous literature has contributed to recognize various approaches in greening the supply chain, litter is known about the consistency and priority approaches, particularly in electronics industry. The main strengths of this paper, hence, are two-folds: It recognizes the consistency approaches and provides a method for ranking approaches. This study proposed the use of FAHP to rank different approaches of GSCM implementation in Taiwanese electronics industry. Despite focusing on the Taiwanese electronics industry, the results of this study provide an insight into recognizing and prioritizing the approaches for implementing GSCM. It also proposed a generic hierarchy model for assessing the relative importance of identified approaches that would affect the GSCM implementation and the development of GSCM strategy and practice. Different organizations can make use of the model in accordance with their specific situations and needs. In addition, the model also can help managers improve their understanding of GSCM practices and enables decision makers to assess the perception of GSCM in their organization. Although the sample in this study was insufficient, it is hoped that it can serve as a base for further research on exploring the implications of GSCM for different industry sectors and regions. The approaches for implementing GSCM in electronics industry should be transformed to accompany changes of environmental regulations and customers in future research. In addition, it is also worth mentioning that supplier management plays the crucial part of implementing GSCM, the buyer-supplier relationships affect GSCM implementation to address the related issues. Furthermore, the application of analytical tool in determining weights for various approaches of GSCM practice is suggested to utilize analytic network process (ANP) in terms of feedback systematic and interdependencies property.

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