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Selecting Green Suppliers with Analytic Hierarchy Process for Biotechnology Industry

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Abstract

The biotechnology industry is recognized as one of the industries of the 21st century with the most potential. The Taiwanese government accordingly has included the biotechnology industry as part of the project entitled "Two-Trillion-Twin-Stars". Under current environmental protection regulations, the pressures related to the green industrial revolution are being intensified. Enterprises collaboratively executing green supply chain management with suppliers are urgently needed. One crucial step of supply chain management is to select appropriate partners. Green supplier selection is conducted by embedding the environmental protection concept within supplier evaluation processes. The primary intention of this study is to investigate the selection process for green suppliers in the biotechnology industry via utilization of the analytic hierarchy process (AHP). The research study collaboratively establishes a set of green supplier evaluation criteria and designs the evaluation processes. In short, the objectives are twofold: (1) to establish collaborative evaluation criteria of green suppliers utilizing AHP; and (2) to construct evaluation processes according to the aforementioned set of criteria. The findings of this research suggest that the major concerns in terms of green supplier selection for biotechnology companies are currently cGMP certification, established environmental policies, and product acknowledgement. Also, an evaluation form consisting of green criteria and weights is constructed to facilitate the selection process.

Keywords*: Green supply chain, Green supplier selection, Analytic Hierarchy Process, Biotechnology industry*

1. Introduction

In recent years, the hi-tech industry has been greatly supported by governments, and a great deal of talent and funds have been absorbed into several relative fields. John Naisbitt (1990) pointed out in Megatrends 2000 that the biotechnology revolution was one of ten trends that influenced peoples' lives in the 1990s. The biotechnology industry is a kind of sunrise industry, as it requires relatively low energy consumption and high knowledge intension, and offers high added value. According to a forecasting report of the Industrial Economics and Knowledge Center at the Industrial Technology and Research Institute (ITRI), the global biotech market grows at 18% per annum on average. According to forecast of the Industrial Development Bureau at the Ministry of Economic Affairs, biotechnology annual output in Taiwan would amount to $3 billion USD, equivalent to NT$ 108.2 billion. Thus, the Taiwanese government included it in the "Two-Trillion-Twin-Stars" project as a national key developing industry in 2002, and has invested NT$150 billion since then to boost the Taiwanese biotechnology industry (MOEA, 2006). In the next five years, the biotechnology industry turnover is expected to grow at 25% per annum on average, driving a NT$150 billion investment. Further, over 500 biotechnology companies will have been founded during this ten-year period (MOEA, 2006). However, the issue of environmental protection gradually becomes important for biotechnology companies, in terms of new product R&D and manufacturing processes, especially the impacts of water and air pollution (Shief, 2006).

Supporting enterprises with technology needed for green supply chains is one way to raise industry competence. With the looming of a green industry revolution, enterprises must be environmental-friendly, and must collaborate with both upstream and downstream supply chain partners. Green supply chain management (GSCM) was first proposed in 1970s. However, scholars and entrepreneurs plunge into its study until 1990s. The concept of GCSM can be simply defined as: an enterprise that collaborates with suppliers to improve products or manufacturing processes so as to raise environmental performances of suppliers and customers (MOEA, 2006).

Since 1999, many theoretical studies and practical cases on green supply chain management in Europe and the US have appeared. One key reason that green supply chain management has become a worldwide phenomenon is that consumers, investors and governments have all become more concerned about environmental protection work. Amongst globalization trends, all large-scale manufacturers have integrated upstream and downstream supply chains one after the other in order to achieve cost-saving in an efficient way. Relationships between supplier and manufacturer are no longer traditionally hostile battles, but have evolved into partner relationships (Lin, 2002). Cooperation with fewer suppliers can ensure a high quality yet low cost supply source; therefore, supplier selection has become more important. In terms of the green supply chain issue, green information and communication systems, environment quality management systems, green product design management, and green supply chain audits are all linked to each other. Therefore, some European Union (EU) countries have begun to focus on cross-link relationships regarding supply chains, and have transformed everlasting environmental protection demands to activate legislation aimed at encouraging involvement of all interested parties (including final consumers) through a market guided system to extend producer responsibility.

The choice of an appropriate cooperative partner is at the heart of supply chain management, and material or product/service providers are the most closely associated with an enterprise. If we can find a supplier that complies with industry characteristics and meets supply chain requirements, then supply chain competence can be enhanced; on the contrary, adding improper suppliers to the supply chain disables the collaborative operation of the whole supply chain, which either causes delays in terms of delivery and production planning, or causes credit and financial losses. Therefore, evaluation of appropriate suppliers is a basic step in terms of supply chain management. In the existing literature, the supplier evaluation for biotech industry was seldom discussed. In practice, efficient supplier evaluation operations are difficult to perform in the biotechnology industry and a set of evaluation systems need to be built that consider the concept of environmental protection. In this study, we derive green supplier evaluation criteria and develop an evaluation model for biotechnology industry to overcome abovementioned difficulties.

The objective of this study is to develop a green supplier evaluation model for the biotechnology industry. Specifically, the objective is twofold: (1) to establish collaborative evaluation criteria of green suppliers utilizing AHP; and (2) to construct evaluation processes according to the set of aforementioned criteria. Based on industry interviews, this study analyzes how manufacturers perform green supplier evaluations, and further design an evaluation form with standard evaluation procedure. Based on the related literature, we investigate the green criteria required by a company during green supplier evaluation, which helps us understand how to build a green evaluation criterion structure and supplier evaluation model. Finally, when building the supplier evaluation criterion structure, we build evaluation criteria into a systematic hierarchy structure with the help of AHP.

2. Literature Review

2.1 Green Supply Chain Management

Supply chain management refers to utilizing, from the upfront supplier to the end consumer, a series of efficient operations to integrate product-related material planning and control, based on the interests of all members in the channel including suppliers, manufacturers, warehouses and retailers. By increasing customer service levels with management skills, existing resources can be fully used and whole system costs can be minimized (Chen & Chen, 2001). The objective of supply chain management is to integrate markets, distribution networks, manufacturing processes and purchasing events in all nodes of the whole supply chain, to realize high level yet low cost customer service, and thereby enlarge competitive advantages. Supply chains expand the original logistic system by not only extending conventional vertical integrated logistics, but also by surpassing logistics through taking full account of the whole logistic process and various environmental factors affecting the process (Juang et al., 2006).

Webb (1994) pointed out that product manufacturing had to use environmental criteria to choose appropriate raw materials, and had to pay attention to recycling and the green purchasing concept as well. Beamon (1999) suggested that environmental factor must be introduced to the supply chain model to put forward wider supply chain design methods. The green supply chain generally refers to supplier product and environmentally related management, or to incorporating environmental protection principles into supplier management systems, the purpose of which is to enhance market competence by implanting more environmental protection concepts. In practice, some companies propose environment-specific purchasing schemes, as well as performance or evaluation processes, to make all or most suppliers follow, while other companies list types of environmentally hazardous substances, and require that no substance on the list exist within materials or components.

Kuo et al. (2004) indicated that, in the whole process of supply chain management, the combination of the process, the products, the packaging, and the distribution have to take environmental problems into account, not only by reducing the social burden on the environment, but also by meeting environmental laws, and lowering green trading barriers. Lai (2004) suggested that building green supply chains has become a major challenge, but that the trend of providing green products can allow us to advance towards a sustainable society. Further, component or material suppliers must consider environmental protection related system besides existing management system; in other words, they must propel green supply chain management methods.

2.2 Supplier Evaluation Methods

In traditional buyer and supplier relationships, each party protects itself, and rarely considers using close cooperation to achieve higher profits. As a result, both buyers and suppliers compete for price advantages in transactions, in order to have the lowest production cost. Their associations are mostly in terms of short-term contracts. Such a price-driven philosophy leads to limited communication between buyers and sellers during transactions, and only rare instances of sharing technical information (Spekman, 1998). In fact, often bilateral hostile relationships are the result due to less trust among manufacturers. Stuart & McCutcheon (1995) discussed building buyer-and-supplier relationships in one conceptually empirical investigation. Newman (1989) and Rubin & Cater (1990) pointed out that, in contrast to short-term contracts, bilateral relationships between buyers and suppliers allow both parties to move closer under a long-term strategic coalition. Blenkhorn & Noori (1991) and McCutcheon et al. (1997) suggested that good cooperation between buyers and suppliers leads to more rapid information exchange, which in turn generates greater environmental adaptivity and flexibility for organizations. All of the above literature stresses successful buyer-and-supplier relationships, and key factors pertaining to collaborative trading relationships.

Choosing appropriate collaborative partners is the most important step for supply chain management, while materials or service providers are the most closely associated with the enterprise. Finding suppliers that comply with industry characteristics and can satisfy the supply chain demand enhances supply chain competence

Table 1. Studies of Supplier Evaluation and Methods

Method	References
Weighted Linear Model	Wind & Robinson (1968), Lamberson et al. (1976), Timmerman (1986)
Group Analysis	Hinkle et al. (1969)
Matrix Model	Gregory (1986)
Linear Programming	Turner (1988), Pan (1989), Ross (2001)
Multi-objective Programming	Muralidharan (2002), Wang (2004)
Mixed Integer Programming	Kumar (2004)
Cost of Ownership Analysis	Ellram (1995), Degraeve (2000), Bhutta (2002), Crama (2004)
Judgmental Model	Patton (1996)
Principal Component Analysis	Petroni & Braglia (2000)
Interpretive Structural Model	Mandal & Deshmukh (1994)
Statistical Analysis	Mummalaneni et al. (1996), Muralidharan (2001)
Neural Network	Siying et al. (1997)
Extenics System	Su and Zhang (2001)
Data Envelopment Analysis	Weber and Desai (1996), Weber (1998), Narasimhan (2001), Talluri et al.(2005),
Analytic Hierarchy Process	Narasimhan (1983), Nydick & Hill (1992), Mohanty & Deshmukh (1993), Barbarosoglu & Yazgac (1997), Ghodsypour (1998), Chien(2000), Bhutta (2002), Sarkis (2002)
Fuzzy Analytic Hierarchy Process	Buckley (1985), Lee(2002), Lai(2004)
Voting Analytic Hierarchy Process	Liu & Hai (2005)
Criteria Confirmation Analysis	McCutcheon & Hartley (1997), Wang (2004)
Collaborative Planning	Prahinski (2004), Fu (2004)
Life Cycle Evaluation	Geier & Kopke (1998), Scharnhorst et al. (2005)
Environmental Impact Evaluation	Pun et al. (2003), Rodrigues et al. (2003), Alshuwaikhat (2005)

(Bharadwaj, 2004; Chien, 2000; Liu & Hai, 2005). However, adding improper suppliers to the supply chain disables collaborative operations of the whole supply chain, either delaying deliveries and production plans, or causing credit and financial losses. Thus, appropriate supplier evaluations are the most fundamental step to supply chain management.

A wide variety of supplier evaluation methods have been used, including linear programming, multi-objective programming, data envelopment analysis, AHP and fuzzy AHP, etc. Table 1 shows studies pertaining to supplier evaluation methods as well as some literature sources.

2.3 Green Supplier Evaluation

Noci (1997) built a conceptual green supplier evaluation procedure, and summarized environmental protection related issues in the past decade as: (1) manager recommended programs to reduce air irradiation, solid waste, wastewater, and energy loss in terminal pipeline planning; (2) use of environmental protection technology in manufacturing processes to reduce their influence on natural resources; (3) changing operation processes and ecology plan structures in terms of products and service. The study proposed three stages of green supplier evaluation: (1) to acknowledge related stipulations of environmental protection regulations; (2) to acknowledge expected contributions of varied suppliers in terms of each objective; and (3) to formulate a final supplier evaluation process. Goffin et al. (1997) pointed out that previous supplier selection concentrated on issues regarding price, quality and delivery speed. However, in the current global supply chain environment, evaluating supplier requirements has become more encompassing, as strategic considerations including technical expertise, financial capability and aftersale service must also be taken into consideration. Coupled with the execution of some international environmental protection decrees, OEM dominant Taiwanese manufacturers must inevitably take account of environmental protection related regulations during supplier evaluations in order to meet international market demands.

Handfield et al. (2002) indicated that purchasing managers of modern enterprises often consider whether or not suppliers comply with environmental protection related laws and regulations when buying materials or products. The ten easiest and most important environmental protection criteria in purchasing decisions were put forward as a reference for purchasing managers, and three cases were provided that concern AHP. Humphreysa et al. (2003) argued to add environment factors in supplier evaluations, so as to respond effectively to the pressure of environmental protection. In order to help enterprises select green suppliers, a set of Case-Based Reasoning (CBR) means was proposed to build a knowledge system including qualitative and quantitative criteria, and thereby help to select the optimum green supplier. This system allowed enterprise managers to shorten evaluation times, and greatly improved overall decision efficiency. Lai (2004) discussed the topic of green supplier management within the electronics industry, and employing the multi-criteria decision method as the basis of supplier evaluation, established a set of sequential evaluation procedures to facilitate OEM data collection, rating and scoring, as well as adjusted decision weights. Examples of printed circuit board (PCB) purchasing and supply were provided to build a real evaluation model. Tsai (2005) suggested that under WEEE and RoHS regulations, the electronics industry had to break away from past quality-based product specifications, and add environmental protection requirements. Some packagers have begun to establish green supply chains and green purchasing standards to adapt to market demands. The most important part of the supply chain was the evaluation of qualified suppliers. According to green purchasing requirements, the supplier evaluation criteria must be modified. Chang (2005) interviewed manufacturers, and all interviewees regarded the selection of green suppliers as a way to collaborate with international big firms and compete for steady or increasing orders. His study combined expert experience and knowledge, formulated criteria of selecting green suppliers, and provided a scoring criteria of green suppliers for the flexible printed circuit (FPC) industry, so that manufacturers could select appropriate green FPC suppliers. It also provided a reference for the industry, and aided enterprises in finding a profit balance between the environment and company economics.

Handfield et al. (2002) stated that, amid the intensifying pressure of environmental protection, environmental protection criteria had to be taken into account during supplier evaluations. Hence, according to comments made by those who make enterprise decisions and environment experts, the performance indices related to evaluating suppliers were listed, and the easiest and most important evaluation indices for enterprises to evaluate suppliers were highlighted. As environmental protection pressure continues to rise, quality and price are no longer competitive weapons in terms of supplier evaluation, as the most important element is currently not hampering either the environment or consumers. Therefore, evaluation indices have been transformed from earlier quality-based ones to a green-based one that pays special attention to environmental protection. In Taiwan, small-and-medium sized enterprises are the majority, accounting for 97.80% of total enterprises (MOEA, 2006). Under RoHS and WEEE, members of a supply chain system must purchase raw materials that minimally pollute the environment or acquire related environmental protection certification, and suppliers are mandated to supply products compliant with EU directives, or face losing opportunities in the global arena.

3. Research Methodology

This study mainly adopted AHP to analyze the importance of various green supplier evaluation criteria. Thus, related criteria were initially acquired from the related literature, and confirmed by expert interviews. We interviewed biotechnology managers to obtain the reference model for biotechnology manufacturers when evaluating green suppliers. A preliminary questionnaire was made after collecting and processing the literature, followed by discussion with biotechnology manufacturing professionals. The processes included asking experts to rate and score the criteria. Criterion unanimously regarded as important were included, while less important ones were omitted.

AHP is a multi-attribute evaluation method developed in 1971 by Prof. Thomas L. Saaty of Pittsburg University, and it is primarily used to solve decision problems in uncertain situations and with multiple evaluation criteria. Combined with expert discussion, the AHP hierarchy structure can be generated from confirmed criteria. To avoid excessive industry discrepancies between the experts, all experts chosen for this study were senior executives of purchasing or environment engineering departments within the industry. This study included five such experts, who were all senior executives of listed or over-the-counter pharmaceutical firms with years of industry experience, and who all had unique viewpoints on subject of this study. Eisenhardt (1989) pointed out that, when conducting a case study, the case number should normally be between four and ten, as fewer cases hamper theory construction, and more cases become hard to analyze due to the relatively large amount of data. Therefore, this study included senior executives of five firms as interview subjects.

The above procedure can be shown as follows: (1) obtain criteria from literature, and filter them by expert interview to form AHP hierarchy structure; (2) design AHP questionnaire and assess comparative values; (3) compute weight of each criterion, and construct evaluation form as well as operational process.

4. Results and Discussion

4.1 Step 1: Extract Green Evaluation Criteria

After the literature analysis, 24 criteria were induced and tabulated as shown in Table 2. However, to investigate the essential green criteria that significantly affect the evaluation of pharmaceutical product suppliers, in-depth interviews were also performed.

Pharmaceutical products are mainly for human and animal use, and there is high demand for product quality and dose accuracy. In circumstances related to the rising environmental protection pressure, supplier selection must be especially cautious. We chose to focus on the pharmaceutical

Table 2. Criteria Summary

No.	Criterion	Description
1	Environmental protection policy and objective	Formulate environmental protection related policies or plan "product environment quality assurance" and regulation restricted product environment quality objectives
2	Environmental protection certification	Introduce or acquire environment management system certification (e.g.: ISO 14001, ROHS)
3	Information transmission and exchange	Summarize customer environment quality requirements and circulate to business departments, design and technical departments and manufacturing departments
4	Education and training	Draft environment related education and training courses with plans and implementations
5	Environmental protection partner	Formulate and execute environmental protection related criteria along with supply chain members
6	Executive support	Company management support implementation of environmental protection strategy
7	Recycle and reuse	Product R&D consider reusability (material alternatives, decomposable, dividable), and check hazardous substances, if any, for recycling
8	Remanufacturing	Design of recyclable containers, reconstruction, remanufacture
9	Green package	Product package design (e.g., reusable package, high recovery package) complying with recycle requirements
10	Material alterability	Improve material labeling, reduce material types, use similar and compatible materials
11	Green technical capability	Develop alternative materials, products, equipment and methods that alleviate life cycle shocks
12	Usage of environmental-friendly material	Whether or not supplier members use process banned substances in processing and has efficient control of chemical substance data
13	Ability of decreasing pollution	Whether or not product contains waste/toxic chemicals
14	Recycled product treatment capability	Whether or not company is capable of treating recycled products
15	Product acknowledgement	Whether or not customers trust and acknowledge product after purchase
16	Environmental protection mark	Whether or not product design and package have honor of environmental protection mark
17	Customer satisfaction	Whether or not environment management substances are summarized as per customer requirement
18	Procurement of environmental-friendly material	Supplier purchase of material must comply with environmental friendly requirements
19	Acquiring new environmental-friendly technology	Supplier manufacturing process must use new environmental-friendly technology
20	Product redesign cost	List product redesign cost
21	Employee training cost	List staff training cost
22	Management of departmental document	As per "product environment quality assurance system", outline documents and data to be managed by various departments
23	Bill of waste management	Manage various kinds of bills (e.g., chemical bill, laboratory and office supply bill)
24	Environment log	Publish environment log (regular report, edition journals of discharge, energy consumption, accident, impairment)

Table 3. Profile of Interviewed Manufacturers

Company	Founding Year	Capital (NT$ billion)	Major Products	Listed or OTC	Subject Tittle
A	1952	2.9	Human medicine, orthopedic appliance, animal medicine	Yes	General Manager
B	1967	1.5	Western medicine, Chinese traditional medicine, material medicine, animal medicine, biochemical supplement	Yes	Assistant Manager
C	1715	670	Prescription medicine, health product, oral cleaning, prepared medicine	Yes	Regional Manager
D	1988	1.1	Western medicine, Chinese traditional medicine, health food	Yes	Regional Director
E	1993	0.831	Various Western medicines, Western medicine material, antibiotics, serum, vaccine, medical equipment	No	General Manager

industry. The basic data for the chosen manufacturers is shown in Table 3. As for the in-depth interviews, subjects were senior executives serving in this industry, or purchasing supervisors of companies in this industry.

The most significant problems the companies faced are the lack of standard evaluation processes and green criteria to rank suppliers. The green supplier evaluation processes are not performed systematically. The interview material also uncovered many key factors and concerns for developing such a procedure. We thus asked the experts to rate the criteria shown in Table 2. The rating scale ranged from 5 points (very important) to 1 point (not important). If the average score for a criterion was higher than 4, then it was adopted. In total, 14 criteria were selected for further analysis. We divided the 14 criteria into five categories, namely: environmental management system, general management ability, environmental protection ability, environment improvement cost, and environmental protection related documentation.

4.2 Step 2: Build Criterion Hierarchy

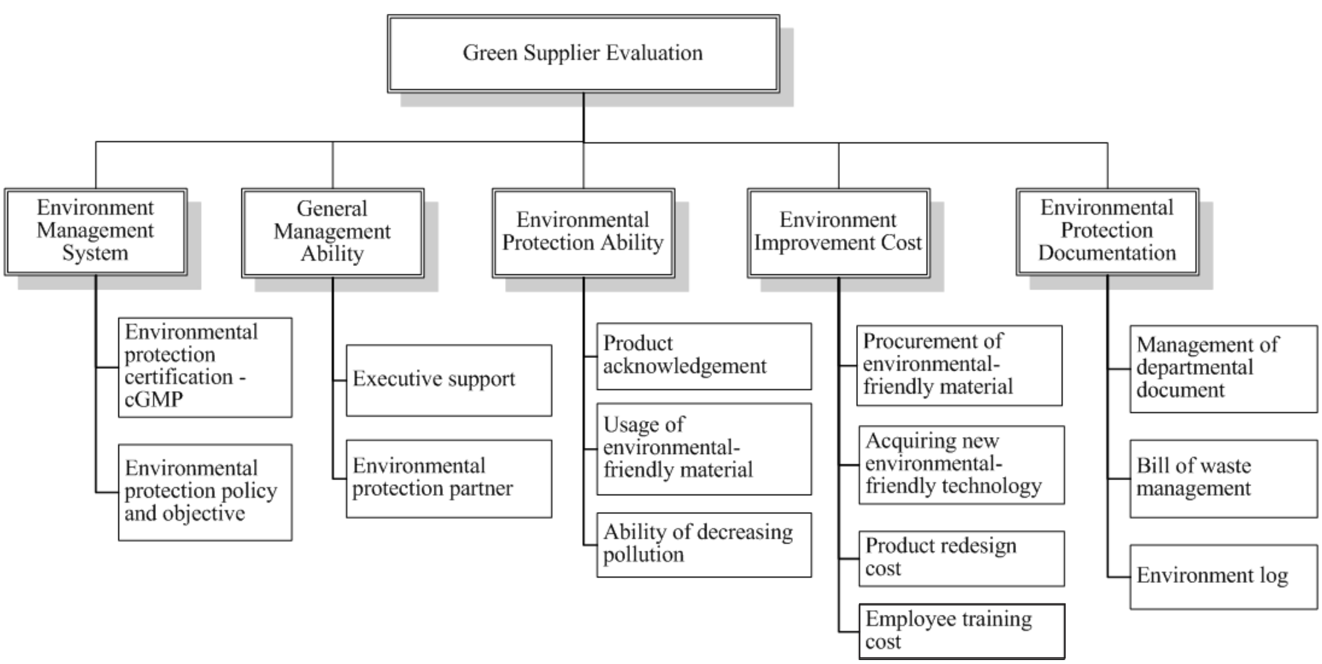
Using multiple criteria, AHP is a simple evaluation method to determine precedence. This study used AHP to confirm the five categories and 14 criteria (cGMP certification, environmental protection policy and objectives, executive support, environmental protection partner, product acknowledgement, usage of environmental-friendly materials, ability to decrease pollution, procurement of environmental-friendly materials, acquiring new environmental-friendly technology, product redesign, employee training cost, management of departmental documents, bill of waste management, environment log). The hierarchy structure was built and is shown in Figure 1.

4.3 Step 3: Calculate the Weight of Each Criterion

This step was divided into four stages: performing interviews based on the questionnaire; establishing a pairwise comparison matrix; computing criterion weights; and calculating consistency.

This study completed the AHP expert questionnaire on the basis of the above criteria. In total, ten experts were interviewed and eight questionnaires were valid, i.e. consistency index, CI<0.1, and consistency ration, CR<0.1. If the number of effective questionnaires had amounted

Figure 1. Criterion Hierarchy of AHP



to three, it would have indicated compliance with the AHP hypothesis (Lin, 2005). The experts interviewed were primarily senior pharmacy executives with decisive power, and they were also knowledgeable regarding environment protection issues. Thus, they were able to express precise and insightful opinions.

The comparison matrix was then established. Once the pairwise comparison matrix was established, the precedence of each criterion could be calculated. After normalization process, the normalized pairwise comparison matrix can be obtained, as shown in Table 4. The criterion score was calculated by averaging the normalized values in each row; these were in turn used to compute consistency measures and a consistency index, and finally the consistency ratio.

4.4 Step 4: Summarize the AHP Questionnaire

We processed the questionnaires into the pairwise comparison matrix one by one, and calculated precedence according to the above steps. Every column in Table 5 represents the weight of each criterion rated by each expert (e.g., the first expert rated environment management systems with a weight of 0.557); every row represents a criterion of each hierarchy in the AHP structure.

AHP uses a consistency ratio to check the pairwise comparison consistency, and if this ratio exceeds 0.1, it indicates inconsistent judgment. In this case, the decision maker had to correct the original values of the pairwise comparison matrix. It was also necessary to check the CI and CR values – if the consistency ratio was less than 0.1, then the pairwise comparison consistency was deemed to be a reasonable level, e.g., for the first expert, CI=0.085<0.1, CR=0.076<0.1.

4.5 Compute the Average Weights

A total of ten experts attended this questionnaire investigation. Two questionnaires with high inconsistency were omitted; hence there were eight effective questionnaires in total. Every hierarchy in each questionnaire has its own weight and consistency ratio. To integrate the questionnaire weights as given by these experts, this study calculated the weight of every criterion in all questionnaires using a weighted average. For instance, the weights of the environment management system criteria as rated by expert 1 thru expert 8 were 0.557, 0.567, 0.386, 0.388, 0.149,

Table 4. Normalized Pairwise Matrix for Main Criterion

	Environment Management System	General Management Ability	Environmental Protection Ability	Environment Improvement Cost	Environmental Protection Documentation	Criterion Score	Consistency Measure
Environment Management System	0.121951	0.078647	0.122804	0.241371	0.1851852	0.149992	9.519056
General Management Ability	0.609756	0.393236	0.6140243	0.241371	0.2592593	0.423529	20.230784
Environmental Protection Ability	0.121951	0.078647	0.1228049	0.241371	0.2592593	0.164807	14.056875
Environment Improvement Cost	0.121951	0.393236	0.1228049	0.241371	0.2592593	0.227725	11.830840
Environmental Protection Documentation	0.024390	0.056233	0.0175611	0.034516	0.0370370	0.033947	0.755350

Table 5. Weights of Criterion Categories and CR values

No.	Environment Management System	General Management Ability	Environmental Protection Ability	Environment Improvement Cost	Environmental Protection Documentation	CI	CR
1	0.557	0.147	0.154	0.090	0.049	0.085	0.076
2	0.567	0.161	0.154	0.075	0.041	0.083	0.074
3	0.386	0.166	0.343	0.051	0.051	0.070	0.060
4	0.388	0.159	0.338	0.071	0.042	0.097	0.086
5	0.149	0.423	0.164	0.227	0.033	0.090	0.080
6	0.276	0.155	0.155	0.184	0.227	0.090	0.080
7	0.348	0.177	0.177	0.222	0.073	0.040	0.040
8	0.557	0.130	0.130	0.130	0.051	0.010	0.010
Total	3.228	1.518	1.665	1.050	0.567	-	-
Average	0.403	0.189	0.208	0.131	0.070	-	-
Rank	1	3	2	4	5	-	-

0.276, 0.348, and 0.557 respectively. These eight weights add up to 3.228, and the average is 0.403. Calculation results of all weights in all categories by all experts are shown in Table 5. It was found that the criterion precedence order was "environment management systems", "environmental protection ability", "general management ability", "environmental improvement costs", and "environmental protection documentation."

4.6 Analyze the Weight of Each Criterion

The overall weight analysis was performed, and the results are tabulated in Table 6. It was found that pharmaceutical manufacturers put a high priority on certification (0.611) and environment protection policies (0.388), which is also why the government has played an active role in tutoring manufacturers to obtain their environmental protection certification; further, pharmaceutical manufacturers insist that environmental protection ability is more important than general management ability, because general management ability can be obtained through training and education. Pharmaceutical manufacturers that lack an ability to protect the environment face having their enterprise image hurt, which can lead to downgraded performance. Further, the environmental protection related documentation criterion was not so highly prioritized because the purchasing process focuses on suppliers' environmental protection ability instead.

It also can be seen that although the criterion weight of executive support (0.512) was greater than the weight of environmental protection partner (0.487), the difference was small. This indicates the importance of executive support in a company, as well as becoming an environmental protection partner along with a supply chain member. In this way, the general management ability of a pharmaceutical factory can be elevated, and consequently the pharmaceutical factory can respond effectively to rising environmental protection pressure, and also acquire more advantages to facilitate overall development.

The weight of product acknowledgement was 0.550, which was the most important among the three criteria in the Environment Protection Ability category. The customer impressions of the purchased product influence the overall image of the company. Therefore, experts demand that product R&D, manufacturing processes, product packaging and final delivery must not threaten the environment. Once a product suggests a negative message to customers, it hampers the company image; hence experts put high emphasis on product acknowledgement. Pharmaceutical factory attention to using environmental-friendly materials and lowering pollution was not as relatively significant, because cGMP certification mandates manufacturers to have regulations related to environmental protection.

Furthermore, it was found that pharmaceutical factories spend considerable investment on developing/procuring new environmental-friendly technology in order to pass the cGMP certification, as medicine manufacturing may contribute to air pollution, water pollution, or solid waste pollution, all of which easily pollute the environment. New manufacturing technology can decrease the above types of pollution, so experts regard the acquisition of new environmental-friendly technology as a must. Furthermore, if products threaten the environment, then pharmaceutical factories must employ countermeasures. In reality, pharmaceutical factories list a sum of costs to deal with these products, or redesign products to meet customer and environment requirements. In this study, experts thought that if products could comply with regulations during the design process, then no additional costs would be needed. Therefore, the importance of buying environmental-friendly material was deemed not so significant due to pharmaceutical factory ecological particularities: drugs are primarily taken by humans or animals, and their necessary ingredients are produced in nature. Thus, the importance of this item was deemed to be less significant. People generally regard employee training very important, but the expert rating of this item suggests that it was not as important, probably due to the fact that companies generally conduct relevant staff environmental education training during meetings. Practically, a company would not want to incur an additional cost to train staff regarding this matter.

As to pharmaceutical factories, the primary criterion regarding environmental protection related documentation was how each department deals with the related documents (0.556), as well as how they deal with purchasing department categorized related waste or purchased green products, in terms of documenting them for supervisors or cGMP certification teams to audit. Manufacturers paid more attention to bills of waste management because related pollutants are discharged in the manufacturing process; therefore, environmental protection engineers must dispose of the waste effectively and document the process for auditing. The environment log was deemed to be less important: if pharmaceutical factories conduct obligated environmental protection practices routinely, big problems are unlikely. However, pharmaceutical factories do not publicize how to dispose of waste or document how substances threaten the environment.

After the weight analysis for each criterion category and each criterion, an overall weight for each criterion was calculated by multiplying the weight of the criterion category and the weight of each criterion. Taking cGMP certification as an example, the overall weight was calculated by multiplying the weight of the criterion category (environment management system), 0.403, by the cGMP certification weight, 0.611, which yielded an overall weight of 0.246. The overall weight and its rank, as shown in Table 6, represent the importance of each criterion in the whole supplier evaluation model.

In short, the top three overall weights were: cGMP certification (0.246), environmental protection policy (0.156), and product acknowledgement (0.114); the sum of these three was 0.516, which is more than 50%. As two of the three were deemed minor criteria according to the environment management system, this indicates the highlighted importance of the environment management system. In addition, if consumers have a good impression of a company after buying a product, enterprise image is further elevated, so this was deemed to be one of the key indices when evaluating green suppliers. The last three criteria were: bill of waste management (0.02), employee training costs (0.015), and environment log (0.01), two of which were in the category of environmental protection related documentation, revealing that the environmental protection documentation of upstream suppliers was less emphasized.

4.7 Construct a Green Suppliers Evaluation Form

Based on the evaluation criteria and their weights, a green supplier evaluation form was proposed as shown in Table 6. By rating each supplier based on the proposed criteria and weights indicated in Table 6, the

Table 6. Green Supplier Evaluation Form

Main Criterion (Weight)	Sub Criterion(Weight)	Rank	Overall Weight (a)	Score(b)	Weighted Score (a*b)	Sub-total
Environment Management System (0.403)	Environmental protection certification – cGMP (0.611)	1	0.246			
	Environmental protection policy and objective (0.388)	2	0.156			
General Management Ability (0.189)	Executive support (0.512)	4	0.097			
	Environmental protection partner (0.487)	5	0.092			
Environmental Protection Ability (0.208)	Product acknowledgement (0.550)	3	0.114			
	Usage of environmental-friendly material (0.186)	8	0.039			
	Ability of decreasing pollution (0.262)	7	0.054			
Environment Improvement Cost (0.131)	Procurement of environmental-friendly material (0.201)	11	0.026			
	Acquiring new environmental-friendly technology (0.441)	6	0.058			
	Product redesign cost (0.238)	10	0.031			
	Employee training cost (0.118)	13	0.015			
Environmental Protection Documentation (0.070)	Management of departmental document (0.556)	8	0.039			
	Bill of waste management (0.291)	12	0.020			
	Environment log (0.148)	14	0.010			
					SUM =	
☐ A. Excellent (90≤SUM≤100) ☐ B. Very Good (80≤SUM<90) ☐ C. Good (70≤SUM<80) ☐ D. Fair (60≤SUM<70) ☐ E. Fail (0≤SUM<60)			Final Decision: ☐ Ready for Placing Order (A,B) ☐ Re-evaluation Needed after Improvement (C,D) ☐ Avoid Placing Order (F)			

suppliers can be effectively evaluated. The supplier evaluation results were divided into groups A, B, C, D and E, according to the summary of weighted scores. Thus, the final decision of whether or not to place an order can be made according to the supplier level: (1) A or B: adequate to place orders, (2) C or D: hold until the supplier makes improvements on environmental protection issues, and (3) E: avoid placing orders.

5. Conclusions

The biotechnology industry is generally regarded as one of the most prospective star industries in the 21st century, and is involved in several key promotion projects in Taiwan, such as "Challenge 2008-National Key Development Program" and "Two-Trillion-Twin-Stars". Environmental protection has gradually become a noticeable issue for manufacturers in new product R&D; therefore, supporting one's company with the technology needed to develop a green supply chain is now a crucial part of enhancing industry competence.

Different enterprises might be located at different levels of the supply chain, and views of one supplier are likely to differ. Therefore, the evaluation model and criteria proposed in this study apply to green supplier evaluation in the biotechnology industry, and can assist firms in their desire to facilitate an overall supply chain operation that complies with environmental protection requirements. In terms of current supplier evaluations, the major focuses of an enterprise remain on the traditional criteria, but in light of rising environmental protection awareness, environmental protection related concepts must be added to supplier evaluations.

Based on the related literature, this study proposed green criteria needed for a green supplier evaluation process, and used practical interviews to analyze how manufacturers conduct green supplier evaluations, so as to build a better green evaluation criterion structure and supplier evaluation process. This study employed the Analytic Hierarchy Process as supplier evaluation method, and calculated relative weights to obtain quantifiable criteria for rating qualified suppliers.

The results are summarized as: (1) the way pharmaceutical factories currently evaluate green suppliers is mainly based on checking whether or not the supplier has passed the cGMP certification, it has established environmental protection policies, and it has product acknowledgements. (2) Based on the expert interviews and literature analysis, this study provides several criteria for biotechnology manufacturers to use when evaluating green suppliers. (3) A model was constructed that details the process of evaluating upstream green suppliers for biotechnology manufacturers. Based on the evaluation criteria and the procedures provided in this study, relative weights for the criteria were calculated, and a green supplier evaluation form was proposed, which can help decision makers to evaluate green suppliers in a more systematic manner.

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