An Empirical Study on Selection, Evaluation, and Management Strategies of Green Suppliers in Manufacturing Enterprises

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ABSTRACT

Green supply chain management means integrating environmental awareness into supply chain management, including product design, raw material acquisition and selection, the manufacturing process, the distribution of final products to customers, and the management of end-of-life products. However, there are driving and unfavorable factors for manufacturing enterprises to choose green suppliers. Therefore, this study proposed a new IPA-DEMATEL model by integrating importance-performance analysis (IPA) and decision-making trial and evaluation laboratory (DEMATEL) to explore green suppliers’ selection, evaluation, and management strategies.

KEYWORDS
Computing, Green Supplier Evaluation, Green Suppliers, IPA-DEMATEL Model

INTRODUCTION

In manufacturing enterprises, the pollution caused by electronic products is becoming serious. Due to the ever-changing functions of electronic equipment and products, their replacement and disposal rate is higher than that of ordinary products. When electronic waste is incinerated or buried without proper treatment, a large amount of harmful substances will inevitably produce a serious impact on the environment. To greatly reduce the environmental load and effectively reduce the impact of motors and electronic equipment products on the environment and human beings, the EU has published the Waste Electrical and Electronic Equipment Regulations (WEEE) and the Restriction of Hazardous Substances in Electrical and Electronic Equipment Directive (RoHS) in 2003 (Beamon, 1999). The WEEE Regulations require all manufacturers selling the above items in the EU to take into account the environmental pollution caused by their product wastes, adopt an environment-friendly design that allows easy recycling, and bear the cost and responsibility of recycling. In addition, the EU also published the Directive of Eco-design Requirements of Energy-using Products (EUP) in 2005. The EUP Directive requires product manufacturers to adopt the thinking mode of life cycle and
integrate the requirements of Eco-design into product design and development to improve product efficiency, reduce energy demand, improve energy efficiency, and meet high environmental protection requirements (Arentze and Timmermans, 2003; Zhu et al., 2007).

Furthermore, there are both driving and unfavorable factors for manufacturing enterprises in choosing green suppliers (GS). As a driving factor, green suppliers can establish the image of providing safe and reliable products and attaching importance to social responsibility, which can help improve the company’s green image and win the favor of customers. However, although green suppliers can improve the utilization efficiency of resources and reduce costs to a certain extent, green recycling and waste treatment will cost them a huge price, with the final cost running behind the suppliers’ expenses (Blome et al., 2014). These problems in management and decision-making cannot be solved only by a single research method.

Furthermore, this study suggested that with the increasing awareness of environmental protection, enterprises should pay more attention to the greening degree of their products and increase the damage evaluation on products to the surrounding environment. At the same time, it is necessary to study the green supplier selection model. Zhu and Sarkis (2004) mentioned that the dimensions of green design, green procurement, green management, green production, and reverse logistics in a green supply chain require further investigation. Hervani et al. (2005) pointed out that the green supply chain mainly comprises green procurement, green manufacturing, green distribution and marketing, and reverse logistics. Tsai et al. (2016) suggested that the four evaluation dimensions of the green supply chain include (1) green design, (2) green production, (3) green marketing, and (4) green recycling. Although the four major processes are considered general principles, their importance and degree of application vary in different countries and enterprises.

There are two major deficiencies in the traditional studies on the evaluation criteria of green suppliers of manufacturing enterprises. On the one hand, some studies assume that the evaluation criteria have equal weights without any difference. On the other hand, most studies assume that evaluation criteria are independent of each other—there is neither a mutual influence nor causal relationship among them.

Based on the research background presented above, this study raises the following three research questions:

1. **Use Importance**: Performance Analysis to evaluate the importance and satisfaction of various evaluation criteria of green suppliers.
2. **Use the Decision**: Making Trial and Evaluation Laboratory to evaluate the causality and mutual influence of various evaluation criteria of green suppliers.
3. **Integrate the Importance**: Performance Analysis with the Decision-Making Trial and Evaluation Laboratory to put forward strategic suggestions for green supplier management.

**LITERATURE REVIEW**

**Green Supply Chains and Green Suppliers**

According to the US Supply Chain Council (SCC), the supply chain covers all activities from manufacturing to distributing the final product to customers. In other words, it is a series of processes commencing from ordering, order management, supply and demand management, raw materials, manufacturing and assembly, warehousing and transportation, and the distribution to channels to the final distribution of products to consumers (Chopra, 2004). Its purpose lies in effectively managing resources to meet customer needs and achieve enterprise goals, such as improving enterprise competitiveness and enterprise operations. However, with the rapid development of technology, the issue of environmental protection must be considered in the entire supply chain management. Furthermore, the original supply chain system has witnessed great changes with the strict requirements
of countries around the world for products’ environmental quality. Many international manufacturers have begun to pay attention to the role of environmental issues in supply chain management. The concept of green supply chain management originated in the 1970s, but it was not until 1990 that experts and scholars conducted in-depth research, which was confined to the concept of environmental protection. It was also not until 1999 that empirical analysis and theoretical basis began to appear (Guo et al., 2015).

The driving forces of green supply chain management can be divided into primary and secondary forces, which can be further sub-divided into internal and external forces. These forces allow enterprises to develop green supply chains and benefit from implementing green supplier management. In terms of internal management, the primary driving forces serve as the basis for risk management and the verification of regulations. On the other hand, in terms of external pressures, these driving forces encompass the improvement of product images, the restrictions and requirements of international purchasing terms, and customer needs. Meanwhile, in terms of internal management, the external driving forces reduce the manufacturing cost and improve the quality of suppliers. On the other hand, in terms of external pressures or benefits, these forces promote innovation (Tsai et al., 2016):

1. **Risk Management**: Risk management is one of the driving forces or benefits of green supply chain management. There are types of risks that should be managed. A. Risk of supplier disruption. Suppliers may be hindered or suspended from manufacturing due to violations of certain laws and regulations; thus, a careful selection of suppliers will reduce the risks of supplier disruption. B. Long-term risks. The suppliers’ emissions and waste volume may affect human health and the environment; thus, paying attention to suppliers’ environmental performance will reduce long-term risks. C. Risk involves non-competitive advantages. Other competitors and peers may implement green supply chain management to obtain competitive advantages in process improvement or product innovation. If some enterprises do not have this competitive advantage, it will greatly affect them.

2. **Improvement of a product image**: Environmental issues or accidents by the company and its products may cause harm to the company’s public image. Thus, companies are making it easier to develop a sound organizational culture within their companies to ensure and maintain an excellent image—a necessary condition for building a brand manufacturer.

3. **Regulatory pressure**: Regulatory pressure pertains to a company’s desire to exceed regulatory requirements. Although regulatory pressure is primarily external, the company’s response comes from its own decision. Enterprises with high self-expectations will pursue higher regulatory requirements. Avoiding suppliers that deliberately or unknowingly supply faulty parts and components requires not only the company’s own efforts but also the joint efforts of upstream and downstream manufacturers. If the company wants to cope with it freely, it should make long-term preparation and risk planning in responding to the pressure of laws and regulations.

4. **Consumer pressure**: Consumers ask companies to tell them who their supplies are, which can deepen suppliers’ awareness of their responsibility for supplying components, especially products with high environmental requirements.

5. **Restrictions and requirements of international purchasing terms**: Eco-labels are globally adopted, and the Extended Producer Responsibility (EPR), WEEE, and RoHS are implemented by the EU to promote green procurement actions and drive the market of environment-friendly brands and various activities.

6. **Cost reduction**: If the suppliers are integrated into the product and the process design of enterprises, at least the low-cost benefits of cost, quality, and distribution can be obtained.

7. **Quality improvement**: Although improving quality is not the main requirement of green supply chain management, once the enterprise implements green management, the quality of products and services will naturally be improved.
8. **Innovation enhancement**: Although green supply chain management does not focus on innovation as its main purpose, sharing goals and efforts between enterprises and manufacturers in the entire supply chain will enhance the innovation of products and processes, improving efficiency.

**Selection of and Evaluation of Green Suppliers**

Hervani et al. (2005) advocated that the green supply chain mainly comprises green procurement, green manufacturing, green distribution, marketing, and reverse logistics. To be environmentally conscious, it is obviously necessary to carry out environmental protection design (sales and design) in the supply chain process, implement green procurement (certified suppliers, and the procurement of raw materials and products that are not harmful to the environment), conduct general environmental quality control (internal performance measurement and pollution prevention), implement environment-friendly material packaging and transportation, and reuse, re-manufacture and recycle discarded products. Hervani et al. (2005) particularly emphasized several factors of green supply chain management, including environment-friendly design, environment-friendly materials, manufacturing, recycling, and environmental performance evaluation.

Srivastava (2007) posited that green supply chain management means integrating environmental awareness into supply chain management, including product design, raw material acquisition and selection, the manufacturing process, the distribution of final products to customers, and the management of end-of-life products.

Tsai et al. (2015) showed that due to the international trend of green products, the departments of sales, customer service, R&D, manufacturing, quality assurance, materials, and environmental safety of many manufacturers in various supply chain systems are constantly being inquired and required by their customers to establish a green supply chain management system. They are also asked to provide documents, such as a third-party testing report on the products, material composition lists, material dismantling lists, product recovery rate calculation, product dismantling manuals, and declaration of conformity regarding the non-use of restricted substances to effectively build and integrate a green supply chain. While establishing a green supply chain often faces the pressures of green products from customers or regulations, some suppliers lack direct environmental pressures and the incentives of investment benefits. More so, suppliers tend to be inactive or unwilling to cooperate when the green supply chain is in the process of establishing or when relevant evidence is required.

The central factory can replace suppliers that are less willing to cooperate. However, if they encounter an oligopolistic or monopolistic strong supplier—in addition to continuous communication and coordination—they also need to seek new cooperative suppliers or change product design. Suppliers with a high degree of cooperation will have a good effect on establishing a green supply chain (Wu, 2021). However, although some small and medium-sized suppliers are willing to cooperate, they also get caught up in a dilemma due to resource constraints or lack of talents. In this case, they must be assisted by brand leaders or large manufacturers (Hsu et al., 2012; Lan et al., 2013; Guo et al., 2015). Tsai (2014) proposed four evaluation processes of a green supply chain, including (1) green design, (2) green production, (3) green marketing, and (4) green recycling. Although the four processes are considered general principles, their importance and degree of application will vary in different countries and enterprises.

Xu et al. (2013) used the Analytic Hierarchy Process (AHP) to divide the supplier evaluation into three aspects: processes, products, and supplier environmental management. The criteria for the environmental performance of a certain process include air pollution discharge, wastewater discharge, solid waste, hazardous material use, energy use, and material use. On the other hand, the criteria for the environmental performance of management include the certifications of ISO14000 series, the companies’ public environmental records, vocational training in environmental-related fields, the environmental performance evaluation on upstream suppliers, the relations with customers and
shareholders, environmental reports, and the company’s clean manufacturing technologies. Further, in terms of the environmental performance of the products, the criteria include product recycling and the environmental design of the packaging.

Wu (2021) pointed out that many leading manufacturers (such as Apple, Samsung, Lenovo, Sony, Dell, and Epson) have devoted themselves to building a more rigorous green product supply chain compliant with regulations, which opens a competition among enterprises. Hence, many supplemental management policies and systems have been developed to guide these policies, including:

1. Providing a complete list of prohibited and restricted reference materials.
2. Building cross-organizational information platforms, some of which use the latest network information platforms.
3. Establishing more professional review standards for production plants.
4. Establishing new criteria for environmental performance evaluation and control.
5. Requiring all suppliers to provide green materials, parts, and products with high standards.
6. Announcing new methods and standards for product acceptance and rejection, quality control, and testing.
7. Requiring upstream suppliers to establish an environmental management system.

This study suggested that supply chain management refers to the cooperation of manufacturers on the supply side and the demand side, aiming to achieve efficiency. On the other hand, green supply chain management refers to the reduction of raw materials, cyclic utilization, recycling, and the substitution of toxic substances by manufacturers on the supply side and the demand side. The activities of green supply management are basically green management for both manufacturers’ internal and external organizational functions.

Based on the previously discussed research on green suppliers, this study divided the evaluation of green suppliers into four dimensions, including A. “The performance of green processes”, B. “The performance of environmental management”, C. “The performance of green management”, and D. “The performance of green products”. In addition, the study also presented ten evaluation criteria. Please refer to Table 1 as shown below for details.

RESEARCH METHOD

This study integrated the importance-performance analysis (IPA) and the decision-making trial and evaluation laboratory (DEMATEL) into a new IPA-DEMATEL model. First, IPA was used to explore the Importance and Performance of the green supplier evaluation criteria of the selected case companies. Then, DEMATEL was adopted to calculate the degree of mutual influence and causal relationship between the green supplier criteria. Finally, the strategic suggestions for green supplier management were put forward.

Importance-Performance Analysis

Martilla and James (1997) were the first to propose the basic framework of the importance-performance analysis and put it into practical use. The IPA is employed to draw the average scores of particular criteria in terms of importance and performance in a two-dimensional graph. The vertical axis represents Importance, while the horizontal axis represents Performance, as shown in Figure 1.

The IPA method can be divided into the following steps. First, all criteria of the research questions are listed and developed into a questionnaire so that users can evaluate these criteria in terms of Importance and Performance. Importance refers to the user’s attention to the criteria, while Performance refers to the performance of product providers or service providers in terms of these criteria. Second, Importance is taken as the horizontal axis and Performance as the vertical axis. Each
analysis attribute is marked in the graph; the priority and selection of various resource allocations can be obtained according to the quadrant in which they are located. Noteworthy, the visualization of options makes it easier to assist in judgment because different positions in the quadrants represent different urgency for improvement (Martinla and James, 1977).

Furthermore, the four quadrants in the IPA method have their own definitions:

1. **Keep up the good work**: It means that customers attach great importance to the criteria in this quadrant and are satisfied with the performance of an enterprise. Therefore, the criteria in this quadrant belong to “keep up the good work”.

2. **Concentrate here**: It means that customers attach great importance to the criteria in this quadrant but are not satisfied with the performance of the enterprise. Therefore, the criteria in this quadrant belong to “concentrate here”.

3. **Low priority**: It means that customers are not satisfied with the performance of an enterprise and do not find the criteria important. Therefore, the criteria in this quadrant belong to “low priority”.

4. **Possible overkill**: It means that although customers do not pay attention to the criteria of this quadrant, they are still satisfied with the performance of the enterprise. Therefore, the criteria in this quadrant belong to “possible overkill”.

By dividing different quadrants, managers can maximize their limited resources and provide priorities to improve satisfaction. The IPA is a method that can easily analyze the quality of criteria and the methods of improvement. It is widely applied by many scholars in other fields as a tool to analyze the priority of criteria improvement and meeting customer needs.

**Importance-Performance Analysis**

Decision-Making Trial and Evaluation Laboratory (DEMATEL) is a human and natural science program developed by the Battelle Memorial Institute of Geneva Research Center. Gabus and Fontela (1973) originally aimed to solve the world’s complex problems, such as those concerning race, hunger, environmental protection, and energy. Initially, there were three main research fields: (1) studying the structure of world problems; (2) analyzing and developing adaptation methods in response to complex world problems, such as problems of race, hunger, environmental protection, and energy; and (3) reviewing the research, models, and materials on world problems.
The DEMATEL directly compares the interrelationships among the criteria of a complex and difficult system and uses matrix operation to calculate the causality and the influence degree of the criteria. Through the direct-relation graph, the influence degree between the elements in the system can be explained with the decimal place representing the influence degree. The complex problems are structured through a cause and effect graph, in which all criteria are divided into the cause and result categories. Quantifying the interaction degree of quality characteristics can contribute to identifying the core problems in a complex system and the direction of improvement (Tzeng et al., 2007; Lee et al., 2010; Lee and Hsieh, 2011).

Employing the DEMATEL effectively helps understand complex causalities. The intricate relationships behind problems can be evaluated and quantified by observing the degree of pairwise influence among elements. Then, the matrix and related mathematical theories are used to calculate the causality and the influence degree among all elements. Finally, appropriate solutions and possible strategies are selected to address the primary and secondary problems. Over the years, the DEMATEL has been widely used to solve various problems in different fields. In particular, its related applications are also wide, including corporate planning and decision-making, developing industrial areas and evaluating environmental conservation plans, analyzing global problems, urban planning and design, geographical environment evaluation, and complex system analyses and evaluations (Wu and Lee, 2007; Wu and Tsai, 2018).

In this study, the structure and operation steps of the DEMATEL are summarized as follows (Wu, 2021).

**Define Criteria Characteristics and Provide Suggestions on Measurement Scales**

Various tools and methods are adopted, such as brainstorming, consulting experts’ opinions, and conducting a literature review to list and define various criteria that may influence the performance of complex systems. In other words, the pairwise interrelationships between two criteria are explained accordingly. Next, the measurement scale for the pairwise comparison between criteria is established. Notably, there is no special specification or limitation in selecting measurement scales.

**Establish a Direct-Relation Matrix**

If there are n kinds of criteria affecting a complex system, through the relevant experts’ opinions, the n kinds of criteria can be made into an n x n Direct-relation Matrix X according to the mutual influence and the influence degree. In the Direct-relation Matrix X, Xij represents the degree of influence of Criterion i on Criterion j, and the Diagonal Criterion Xii of the Direct-relation Matrix X is set as 0:

\[
X = \begin{bmatrix}
0 & x_{12} & \cdots & x_{1n} \\
x_{21} & 0 & \cdots & x_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
x_{n1} & x_{n2} & \cdots & 0
\end{bmatrix}
\] (1)

**Calculate the Normalized Direct-Relation Matrix**

In calculating the Normalized Direct-Relation Matrix, Lin and Wu (2008), Lee et al. (2010), and Lee and Hsieh (2011) used the column vector and the largest value as the normalization benchmark. Definition:

\[
\lambda = \frac{1}{\max_{1\leq i \leq n} \left( \sum_{j=1}^{n} x_{ij} \right)}
\] (2)
Then, the Direct-relation Matrix $X$ is multiplied by the $\lambda$ value, and the Normalized Direct-relation Matrix can be obtained:

$$N = \lambda X$$

(3)

**Calculate the Direct-Indirect Matrix**

When a known Normalized Direct-relation Matrix $N$ is obtained, the Identity Matrix $I$ can be used to obtain the Direct-indirect Matrix $T$, also known as the Total-Relation Matrix:

$$T = \lim_{k \rightarrow \infty} \left( N + N^2 + \cdots + N^k \right) = N \left( I - N \right)^{-1}$$

(4)

Specifically, $I$ is the Identity Matrix.

**Calculate the Influence Degree of the Factor and the Degree of Its Being Influenced**

After the Direct-indirect Matrix $T$ is obtained, the influence of a criterion on other criteria and the degree of its being influenced by other criteria must be calculated. First, the $t_{ij}$ can be defined as the criteria characteristics in the Direct-indirect Matrix $T$, where $i, j = 1, 2, \ldots, n$. Next, the $D_i$ can be taken as the sum of the $i$-th column, which means that Criterion $i$ is the cause and the sum of its influence on other criteria. On the other hand, $R_j$ can be taken as the sum of the $j$-th column, which means that Criterion $i$ is the result and the sum of the influence of other criteria on it. Both $D_i$ and $R_j$ obtained from the Direct-indirect Matrix $T$ include direct and indirect effects:

$$D_i = \sum_{j=1}^{n} t_{ij} \quad (i = 1, 2, \ldots, n)$$

(5)

$$R_j = \sum_{i=1}^{n} t_{ij} \quad (j = 1, 2, \ldots, n)$$

(6)

**Calculate the Prominence and Relation**

$(D_i + R_i)$ is defined as prominence, and $k = i = j = 1, 2, \ldots, n$, which represents the total influence degree of this criterion and the degree of its being influenced by other criteria. The value of the $(D_i + R_i)$ can show the prominence of Criterion $k$ in all problems. Meanwhile, $(D_i - R_i)$ is defined as the relation, which indicates the degree of difference between the influence of this criterion and the degree of its being influenced by other criteria. The value of $(D_i - R_i)$ can indicate the relation of Criterion $k$ in all problems. If it is a positive value, the criterion is biased to the cause category; otherwise, it is biased to the result category.

**Draw a Cause-Effect Graph**

The cause and effect matrix takes $(D_i + R_i)$ as the horizontal axis and $(D_i - R_i)$ as the vertical axis. The purpose of using the matrix is to simplify the complex causality into an easy-to-understand visual structure. The location of the criterion determined that the criterion should be classified as the cause category or result category, as well as the influence degree of the criterion and the degree of its being influenced by other criteria. Appropriate decisions should be made to solve the problem according to the category and the influence degree.
When the value of \((D_k - R_k)\) is positive, Criterion \(k\) belongs to the cause category; otherwise, Criterion \(k\) belongs to the result category. The larger the value of \((D_k - R_k)\), the greater the degree to which the criterion influences other criteria and is influenced by other criteria. According to the coordinate position of Criterion \((D_k + R_k)\) and \((D_k - R_k)\), the criteria can be divided into the following four categories:

1. The value of \((D_k - R_k)\) is positive, and the value of \((D_k + R_k)\) is large: the representative criterion belongs to the cause category—the driving factor for problem-solving.
2. The value of \((D_k - R_k)\) is positive, and the value of \((D_k + R_k)\) is small: the representative criterion is independent and can only influence a few other criteria.
3. The value of \((D_k - R_k)\) is negative, and the value of \((D_k + R_k)\) is large: the representative criterion is the core problem that must be solved, but because it belongs to the result category, it cannot be directly improved.
4. The value of \((D_k - R_k)\) is negative, and the value of \((D_k + R_k)\) is small: the representative criterion is independent and can only be influenced by a few other criteria.

According to the above analysis, decision-makers can find the driving criteria to solve the core problems in complex systems based on the causality of criteria and the degree of mutual influence of the criteria. Furthermore, they can make appropriate decisions to solve the problems according to the category and its degree of influence.

**RESEARCH RESULTS AND DISCUSSION**

**Questionnaire Design**

This study took Taiwan’s printed circuit board industry as the research subject. The wastewater, waste liquid, and waste generated in the manufacturing process of printed circuit boards are of various types. In addition to various organic pollutants, there are also a large amount of heavy metals, such as copper, lead, and nickel, whose pollution intensity is strong. Failures in pollution prevention and control will cause serious environmental pollution. Hence, the recurring concern of enterprises and administrative environmental protection units lies in how they can reduce environmental pollution in the manufacturing process and carefully choose green suppliers.

The four dimensions of green suppliers in this study include (A) “The performance of green processes”, (B) “The performance of environmental management”, (C) “The performance of green management”, and (D) “The performance of green products”. The ten evaluation criteria are as follows: (A1) “Exhaust emission status”, (A2) “Wastewater discharge status”, (A3) “Hazardous waste treatment”, (B1) “Environmental certifications”, (B2) “Continuous monitoring and compliance with regulations”, (B3) “The effect of environmental management systems”, (C1) “Green sales”, (C2) “Green transportation”, (D1) “Green design of products”, and (D2) “Product recyclability”. Please refer to Table 1 for details.

X Company is one of Taiwan’s top ten printed circuit board companies. This study took X Company as the case study subject and evaluated the performance of its green suppliers—the results of which could serve as the basis for improving its management improvement.

This study employed two questionnaires. The first questionnaire was an IPA questionnaire that asked experts about the importance and performance of the evaluation criteria on each green supplier of the case company. A Likert scale with seven points was used for this questionnaire, with a total of ten questions. The second questionnaire was a DEMATEL questionnaire, in which personal opinions on the evaluation criteria for green suppliers were provided by a group of experts. A seven-point scale was adopted as the measurement scale, with “6” representing the highest degree of influence,
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the ten evaluation criteria has not been discussed. Therefore, it is still not possible to fully understand the real causal relationship, mutual influence relationship of the green supplier evaluation criteria, as well as the management coping strategies in this industry.

**DEMATEL Results**

Table 3 shows the survey results of the experts’ opinions. The scores of the 15 experts were averaged, and the scores were rounded to the first decimal place to obtain a questionnaire with ten criteria. There were 100 squares in total. After ten diagonal criteria were deducted, the influence degree was zero, and there were 90 mutual influence degrees in total.

The calculation of the Normalized Direct-relation Matrix takes the column vector and the largest value as the normalization benchmark. The reciprocal of the maximum value in the sum of each column was the \( \lambda \) value. According to Eq. (2), the Direct-relation Matrix \( X \) was multiplied by the \( \lambda \)

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### Table 2. The importance and performance of green supplier evaluation criteria

| No. | Content                        | Importance | Performance | Management Strategies       |
|-----|--------------------------------|------------|-------------|----------------------------|
| A1  | Exhaust emission status        | 5.56       | 5.64        | Possible overkill           |
| A2  | Wastewater discharge status    | 5.77       | 5.70        | Keep up the good work       |
| A3  | Hazardous waste treatment      | 5.81       | 5.45        | Concentrate here            |
| B1  | Environmental certifications   | 5.61       | 5.78        | Possible overkill           |
| B2  | Continuous monitoring and      | 5.82       | 5.79        | Keep up the good work       |
|     | compliance with regulations    |            |             |                            |
| B3  | The effect of environmental    | 6.09       | 5.67        | Keep up the good work       |
|     | management systems             |            |             |                            |
| C1  | Green sales                    | 5.18       | 5.37        | Low priority                |
| C2  | Green transportation           | 5.05       | 5.42        | Low priority                |
| D1  | Green design of products       | 6.02       | 5.44        | Concentrate here            |
| D2  | Product recyclability          | 5.72       | 5.48        | Concentrate here            |
|     | **Average:**                  | **5.66**   | **5.57**    |                            |

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### Table 3. The survey results of the experts' opinions

| Criteria | A1 | A2 | A3 | B1 | B2 | B3 | C1 | C2 | D1 | D2 |
|----------|----|----|----|----|----|----|----|----|----|----|
| A1       |    | 0.6| 1.3| 4.5| 2.7| 2.2| 0.4| 0.5| 1.2| 1.3|
| A2       | 0.7|    | 1.2| 4.4| 3.6| 2.5| 0.5| 0.3| 1.1| 0.9|
| A3       | 1.2| 0.5|    | 4.4| 3.4| 2.7| 0.7| 0.6| 0.9| 1.3|
| B1       | 1.4| 1.9| 2.4|    | 3.5| 3.2| 2.5| 2.6| 1.8| 2.5|
| B2       | 2.2| 3.3| 4.5| 5.2|    | 5.1| 1.5| 1.8| 2.8| 3.1|
| B3       | 2.4| 2.8| 3.8| 4.7| 3.6|    | 1.3| 1.8| 3.2| 3.7|
| C1       | 0.6| 0.8| 0.9| 2.3| 2.4| 2.5|    | 4.3| 1.4| 1.7|
| C2       | 1.1| 0.7| 0.8| 1.9| 2.6| 2.8| 2.2|    | 1.6| 0.8|
| D1       | 2.4| 2.5| 1.9| 4.3| 2.5| 1.4| 2.5| 3.7|    | 5.2|
| D2       | 2.3| 2.7| 4.3| 3.2| 2.6| 2.6| 2.7| 2.3| 2.1|    |
value to obtain the Normalized Direct-relation Matrix \( N \), and the influence coefficient was rounded to the second decimal place. Please refer to Table 4.

Then, Eq. (3) and Eq. (4) were used to calculate the Total-relation Matrix \( T \). The total-relation criteria matrix is acquired in Table 5.

Eq. (5) and Eq. (6) were used to calculate the value \( D_i \) of each column and the value \( R_j \) of each row, the Prominence of \( D + R \), and the Relation of \( D - R \). The total influence given and received on dimensions and criteria is summarized in Table 6. In addition, ten criteria can be determined with Prominence as the horizontal axis and Relation as the vertical axis, as shown in Figure 2.

According to the analysis results in Table 6 and Figure 2, the causality and mutual influence degree of the ten criteria of green supplier evaluation are described as follows:

1. **High Relation and Prominence**: These four criteria, including (B2) continuous monitoring and compliance with regulations, (B3) the effect of environmental management systems, (D1) green design of products, and (D2) product recyclability, belong to the cause category. They are the core items that influence other criteria, representing the driving factors for problem-solving.

### Table 4. The initial direct-relation matrix \( X \)

| Criteria | A1  | A2  | A3  | B1  | B2  | B3  | C1  | C2  | D1  | D2  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A1       | —   | 0.02| 0.04| 0.15| 0.09| 0.07| 0.01| 0.02| 0.04| 0.04|
| A2       | 0.02| —   | 0.04| 0.15| 0.12| 0.08| 0.02| 0.01| 0.04| 0.03|
| A3       | 0.04| 0.02| —   | 0.15| 0.12| 0.09| 0.02| 0.02| 0.03| 0.04|
| B1       | 0.05| 0.06| 0.08| —   | 0.12| 0.11| 0.08| 0.09| 0.06| 0.08|
| B2       | 0.07| 0.11| 0.15| 0.18| —   | 0.17| 0.05| 0.06| 0.09| 0.11|
| B3       | 0.08| 0.09| 0.13| 0.16| 0.12| —   | 0.04| 0.06| 0.11| 0.13|
| C1       | 0.02| 0.03| 0.03| 0.08| 0.08| —   | 0.15| 0.05| 0.06|
| C2       | 0.04| 0.02| 0.03| 0.06| 0.09| 0.09| —   | 0.05| 0.03|
| D1       | 0.08| 0.08| 0.06| 0.15| 0.08| 0.05| 0.08| 0.13| —   | 0.18|
| D2       | 0.08| 0.09| 0.15| 0.11| 0.09| 0.09| 0.08| 0.07| —   | —   |

### Table 5. The total-relation criteria matrix \( TC \)

| Criteria | A1  | A2  | A3  | B1  | B2  | B3  | C1  | C2  | D1  | D2  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A1       | 0.10| 0.14| 0.20| 0.37| 0.27| 0.25| 0.12| 0.14| 0.16| 0.19|
| A2       | 0.13| 0.13| 0.21| 0.38| 0.30| 0.27| 0.13| 0.14| 0.16| 0.19|
| A3       | 0.15| 0.15| 0.17| 0.38| 0.30| 0.28| 0.14| 0.15| 0.16| 0.20|
| B1       | 0.19| 0.22| 0.29| 0.32| 0.36| 0.34| 0.22| 0.25| 0.22| 0.28|
| B2       | 0.26| 0.32| 0.42| 0.58| 0.34| 0.47| 0.24| 0.28| 0.30| 0.36|
| B3       | 0.25| 0.29| 0.38| 0.54| 0.42| 0.30| 0.22| 0.26| 0.30| 0.36|
| C1       | 0.13| 0.15| 0.20| 0.32| 0.27| 0.27| 0.12| 0.17| 0.17| 0.21|
| C2       | 0.14| 0.14| 0.18| 0.28| 0.26| 0.26| 0.17| 0.12| 0.17| 0.17|
| D1       | 0.24| 0.26| 0.31| 0.49| 0.37| 0.33| 0.25| 0.31| 0.19| 0.39|
| D2       | 0.23| 0.26| 0.36| 0.45| 0.36| 0.35| 0.24| 0.26| 0.24| 0.22|
2. **High Relation and low Prominence:** Although the (A1) exhaust emission status and (C1) green sales criteria belong to the cause category, their influence degree is small and can only affect a few other criteria. The criteria are independent.

3. **Low Relation and high Prominence:** The (B1) environmental certifications criterion belongs to the result category and is influenced by other criteria. Therefore, it cannot be directly improved.

4. **Low Relation and Prominence:** The criteria, including (A2) wastewater discharge status, (A3) hazardous waste treatment, and (C2) green transportation, are influenced by other criteria. However, the degree of influence is not large, which means that these criteria are relatively independent.

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**Table 6. Summary table of the DEMATEL prominence and relation**

| Criteria | D    | R    | D + R | D - R |
|----------|------|------|-------|-------|
| A1       | 1.94 | 1.82 | 3.76  | 0.11  |
| A2       | 2.03 | 2.05 | 4.08  | -0.02 |
| A3       | 2.08 | 2.73 | 4.81  | -0.65 |
| B1       | 2.70 | 4.10 | 6.81  | -1.40 |
| B2       | 3.57 | 3.25 | 6.82  | 0.32  |
| B3       | 3.33 | 3.10 | 6.43  | 0.23  |
| C1       | 2.11 | 1.83 | 3.94  | 0.27  |
| C2       | 1.88 | 2.19 | 4.07  | -0.31 |
| D1       | 3.15 | 2.06 | 5.21  | 1.08  |
| D2       | 2.94 | 2.57 | 5.51  | 0.38  |
| **Average value:** | | | **5.14** | **0.00** |

**Figure 2. Interrelationships of ten criteria**

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2. **High Relation and low Prominence:** Although the (A1) exhaust emission status and (C1) green sales criteria belong to the cause category, their influence degree is small and can only affect a few other criteria. The criteria are independent.

3. **Low Relation and high Prominence:** The (B1) environmental certifications criterion belongs to the result category and is influenced by other criteria. Therefore, it cannot be directly improved.

4. **Low Relation and Prominence:** The criteria, including (A2) wastewater discharge status, (A3) hazardous waste treatment, and (C2) green transportation, are influenced by other criteria. However, the degree of influence is not large, which means that these criteria are relatively independent.
Among the ten criteria of green supplier evaluation, B2 “continuous monitoring and compliance with regulations”, B3 “the effect of environmental management systems”, D1 “green design of products”, and D2 “product recyclability” have high Relation and Prominence. They are the core items that influence other criteria. Improving these four criteria can solve the core problems and improve the performance and competitiveness of other criteria.

**Discussion of the IPA-DEMATEL Model**

According to the analysis results of the IPA, X Company falls in the quadrant of “Keep up the good work” with (A2) wastewater discharge status, (B2) continuous monitoring and compliance with regulations, and (B3) the effect of environmental management systems. This strength of Company X must be continued and maintained. In combination with the DEMATEL's analysis, (B2) “Continuous monitoring and compliance with regulations” and (B3) “The effect of environmental management systems” fall into the area of “High Relation and Prominence”, which are criteria of the cause category. Therefore, X Company should focus on these two criteria, continue investing resources and staying ahead. Not only that it helps continue to improve the performance of green suppliers, but it also enhances the competitiveness of other criteria. Meanwhile, the (A2) wastewater discharge status criterion is relatively independent and is not easily influenced by other criteria.

According to the analysis results of the IPA, X Company is in the quadrant of “Concentrate here” with (A3) hazardous waste treatment, (D1) green design of products, and (D2) product recyclability. This finding indicates that the company has a competitive disadvantage in terms of these criteria. Therefore, X Company must concentrate resources to improve the performance of these three criteria to compensate for the disadvantage and enhance its competitiveness in green management. In combination with the DEMATEL’s analysis, (D1) green design of products and (D2) product recyclability are both in the quadrant of “High Relation and Prominence”. These two criteria belong to the cause category and are the core items that influence other criteria, representing the driving factors for problem-solving. Therefore, X Company must immediately concentrate company resources to solve the problems in the green design of products and product recyclability; otherwise, the performance of X Company’s green suppliers will lag behind industry standards and competitors, which will be irreversible. Meanwhile, the (A3) hazardous waste treatment criterion falls in the “Low Relation and Prominence” quadrant. Although this criterion can be influenced by other criteria, its degree of influence is very small and relatively independent.

Further, according to the analysis results of the IPA, X Company is in the “Low priority” quadrant with the (C1) green sales and (C2) green transportation criteria. This finding indicates that X Company did not perform well. However, the criteria’s importance was also low. In addition, in combination with the analysis of the DEMATEL, these two criteria are relatively independent, not easily influenced by other criteria, and can hardly influence other criteria. Therefore, it can be placed in the last order. Moreover, when the company has excess resources, it can be improved.

According to the analysis results of the IPA, X Company has good performance in the (A1) exhaust emission status and (B1) environmental certifications criteria, which are located in the quadrant of “Possible overkill”. This finding means that although X Company performed well, it could not bring more performance to the company. In addition, in combination with the analysis of the DEMATEL, these two criteria are relatively independent, not easily influenced by other criteria, and can hardly influence other criteria. Thus, the company no longer needs to invest too many resources.

Based on the discussion results of the IPA-DEMATEL model, a complete green management competition strategy can be proposed for X Company. The status and management strategies of green performance are presented in Table 7.
CONCLUSION

There are both driving and unfavorable factors for manufacturing enterprises in choosing green suppliers (GS). As a driving factor, green suppliers can establish the image of providing safe and reliable products and attaching importance to social responsibility, which can help improve the company’s green image and win the favor of customers. However, although green suppliers can improve the utilization efficiency of resources and reduce costs to a certain extent, green recycling and waste treatment will cost them a huge price, with the final cost running behind the suppliers’ expenses. These problems in management and decision-making cannot be solved only by a single research method.

This study proposed a new IPA-DEMATEL model by integrating Importance-Performance Analysis (IPA) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) to explore green suppliers’ selection, evaluation, and management strategies.

X Company is in the quadrant of “Keep up the good work” with (A2) wastewater discharge status, (B2) continuous monitoring and compliance with regulations, and (B3) the effect of environmental management systems. This strength of Company X must be maintained. Not only that it continues improving its green performance, but it also enhances the competitiveness of other criteria.

X Company has a competitive disadvantage in (D1) green design of products and (D2) product recyclability, which belong to the cause category. They are the core items that influence other criteria, representing the driving factors for problem-solving. Therefore, X Company must immediately concentrate company resources to solve the problems in the green design of products and product recyclability; otherwise, X Company’s green supplier performance will lag behind industry standards and competitors, which will be irreversible.

Table 7. Competitive Situation and Competitive Strategy of IPA-DEMATEL Model of Green Performance

| Competitive strategy | Performance criteria on green suppliers | DEMATEL competitive strategy analysis |
|----------------------|----------------------------------------|--------------------------------------|
| Keep up the good work| (B2) continuous monitoring and compliance with regulations (B3) the effect of environmental management systems. | It falls in the “High Relation and Prominence” quadrant, with the criteria belonging to the cause category. Therefore, X Company should list these two criteria as its key points, continue investing resources and staying ahead. Not only that it continues improving its green performance, but it also enhances the competitiveness of other criteria. |
| (A2) wastewater discharge status | This criterion is relatively independent and is not easily influenced by other criteria. |
| Concentrate here | (D1) green design of products (D2) product recyclability | It falls in the “High Relation and Prominence” quadrant, with the criteria belonging to the cause category. They are the core items that influence other criteria, representing the driving factors for problem-solve. Therefore, X Company must immediately concentrate company resources to solve the problems in the green design of products and product recyclability; otherwise, X Company’s green supplier performance will lag behind industry standards and competitors, which will be irreversible. |
| (A3) hazardous waste treatment | It falls in the “Low Relation and Prominence” quadrant. Although this criterion can be influenced by other criteria, its degree of influence is very small and relatively independent. |
| Low priority | (C1) green sales (C2) green transportation | These two criteria are relatively independent, not easily influenced by other criteria, and can hardly influence other criteria. |
| Possible overkill | (A1) exhaust emission status (B1) environmental certifications | These two criteria are also relatively independent, not easily influenced by other criteria, and can hardly influence other criteria. Thus, it no longer needs to invest too many resources. |
concentrate company resources to solve the problems in the green design of products and product recyclability; otherwise, X Company’s green supplier performance will lag behind industry standards and competitors, which will be irreversible.

However, for the evaluation criteria of green suppliers discussed in this study, only the first-level dimension and the second-level criteria were completed. The other lower-level evaluation criteria were not discussed in detail. Therefore, it is recommended that future researchers include the third or fourth level of evaluation criteria for a more detailed investigation. Moreover, it is suggested that future researchers use the IPA-DEMATEL model developed in this study to select different topics, industries, and cases in developing other evaluation systems and competitive strategy analyses.
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