Fuzzy-DEMATEL based competitive analysis of green suppliers in a supply chain

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Abstract. With the increasingly fierce competition among enterprises, the role of suppliers and core companies has shifted from “competitors” to “partners”. Under such a co-opetition relationship, how to be sustained success in a supply chain without protection or subsidies is a key issue for the survival and development of suppliers. This study aims to explore the factors that influence the competitiveness of suppliers. Based on Baosteel, firstly, this study constructed a hierarchical structure including 3 aspects and 13 factors. After acquiring 12 experts’ assessments, Fuzzy-DEMATEL was employed to process the data. Finally, causal map was plotted according to the outputs. Referring to the causal map, we found that “Green Manufacturing Process” and “Use of Environmentally Friendly Materials” are the most influential factors in term of total influence and net influence. Therefore, these two factors can be regarded as critical factors.

1. Introduction

With the continuous development of the Internet, China has ushered in the best era since the reform and opening up, it is possible to buy needed products without leaving home, which also has driven the rapid development of the manufacturing industry. At the same time, people's consumption has been upgraded and living standards have been improved. Therefore, more attention has been paid to healthy and green living environment, thus the issues that environmental protection and sustainable development are advocated. Due to the rapid development of the economy, the pollution problems brought by the manufacturing industry to the environment have seriously affected people's living environment.

The 21st century is a green era, and protecting the environment is the responsibility of each of us. Countries are also introducing stricter environmental protection policies and strengthening environmental protection and management, for example, the EU officially launched the EU greenhouse gas emission trading scheme (EUETS) in 2005 to control the emission of carbon dioxide (CO2). China joined the World Trade Organization in 2001, and green barriers are an important factor for the survival and development of China's manufacturing industry in the international trading market. In addition, China's environmental protection tax law, which was enacted in January 2018, shows that enterprises is facing stricter environmental requirements, great environmental pressure and the development trend of future green economy. Manufacturing companies are striving to improve the
efficiency of green supply chains. As an important part of the supply chain, upstream suppliers are one of the important factors whether enterprises can effectively achieve the performance of green supply chain. Therefore, what green competitive advantages the upstream green suppliers should have is the main reference indicator for the core enterprises to select suppliers. This paper, through understanding and analyzing the competition factors of green suppliers, aims to find out the key factors that have the greatest impact, and provide some reference when suppliers are developing competitive strategy and core enterprises are fulfilling their green commitments.

2. Literature review

2.1. Green suppliers
In 1966, Dickson GW sent questionnaires to 273 procurement managers to conduct a survey, and sorted out the evaluation factors of suppliers and analyzed the importance of evaluation factors, the results showed that quality is a “very important” factor, and the 9 factors such as price, delivery on time, turnover and so on are “relative important” factor, and the 12 factors such as packaging capacity and corporate attitude and so on are “important” factors, and only one is “less important”, that is reciprocal arrangement. In 1991, Weber performed secondary sort of Dickson's 23 factors by reading 74 supplier selection literatures from 1967 to 1990, the top 10 factors were: price, delivery on time, quality, equipment capability, geographic location, technical capability, management and organization, industry status, reputation and historical performance. In 1997, Noci believed that the supplier's environmental management strategy should be given priority, and gave quantitative evaluation indexes such as enterprise green capability, environmental management efficiency, green image and life cycle, etc. After that, the research on suppliers was added the environmental indexes. In 1998, Walton discussed the criteria for selecting suppliers when considering environmental factors, mainly including these green norms such as disclosure and records of environmental incidents, toxic substances and waste management, compliance with legal requirements, product friendliness and so on. From the above literatures, it can be seen that early scholars' researches on the selection of green suppliers are relatively one-sided, it only considered the impact of enterprises on the environment. And then, through the continuous extension of environmental impact, scholars sorted out more comprehensive evaluation factors of green supplier selection. For example, in 2013, Tseng and Chiu proposed to take environmentally friendly design, green production planning, and green R&D technology and so on as evaluation factors.

2.2. The application of DEMATEL
DEMATEL was first proposed by Gabus and Fontela in the 1970s to analyze the relationship between various factors in complex systems. DEMATEL can more directly identify the importance of various factors in the system and the influence of various factors. Therefore, in recent years, it has attracted the attention of scholars at home and abroad and has been applied in different fields.

Wu and Lee (2007) combined the fuzzy theory and empirical research with DEMATEL to figure out how to decompose certain abilities into parts to enrich the abilities of global managers and further promote the developmental method of global managers' abilities. Wu Hongyi, Zhang Youming and Zhou Jiarong (2014) analyzed professional consumers' purchasing factors and general consumers' purchasing factors by using DEMATEL, obtained the key factors affecting professional consumers to buy sports and casual shoes, and proposed corresponding commercial suggestions for related sports and casual shoe manufacturers. Li Xiaoying and Zhu Qinghua (2015) combined DEMATEL and ANP when establishing the evaluation model of green suppliers. After DEMATEL was used to determine the impact and causal relationship of evaluation, ANP was further used to determine the weight relationship, and they provided a scientific evaluation model for enterprises to choose green suppliers.

3. Research method
Decision Making Trial and Evaluation Laboratory (DEMATEL) was proposed by Fontela and Gabus at the Battelle Association of the Geneva Research Center in the early 1970s. The method combines graph theory and matrix to calculate the degree of influence between complex factors, and then uses numbers to concretely indicate the degree of causal influence between factors, and then we can put forward suggestions through in-depth analysis. Early DEMATEL was mainly used to study difficult and complex world-level problems, such as environmental pollution, resource issues, ethnic issues, etc. Because the DEMATEL method has excellent functions in factor research analysis and specific identification, and now, it is widely used in many fields such as enterprise internal management, market operation, and supply chain, etc.

The using steps as below: establish the system of evaluation factors, use the data of expert scoring, construct the initial matrix, and then normalize the initial matrix to obtain the normalization matrix, and calculate the total impact matrix. Finally, indexes such as centrality and cause degree and so on are obtained by analyzing the total impact matrix. From a mathematical point of view, DEMATEL can be expressed in the following way.

Step 1: Define criteria (impact factor) and establish facets and hierarchical structure of criteria

Step 2: To obtain evaluation the extent to which experts have an impact on pairwise comparisons between criteria

Questionnaire survey was conducted among h experts, and the evaluation data of expert k was obtained and sorted out as: $F_k = [f_{ij}^k]_{n \times n}$, among them, $1 \leq i,j \leq n$, n is the number of criteria, $f_{ij} = 0$, if $i=j$, that is, the diagonal element of F is set to 0.

Step 3: Construct an initial impact matrix

Use $f_{ij} = \frac{1}{h} \sum_{k=1}^{h} f_{ij}^k$ to calculate the initial impact matrix $F = [f_{ij}]_{n \times n}$.

Step 4: Normalize the initial impact matrix

Calculate $\lambda = \min \left\{ \frac{1}{\max_{1 \leq j \leq n} \sum_{i=1}^{n} |f_{ij}|}, \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^{n} |f_{ij}|} \right\}$, among them, $1 \leq i,j \leq n$.

Normalize the initial impact matrix $Z = \lambda F$.

Step 5: Derive total impact matrix

Total impact matrix $T = \lim_{l \to \infty} (Z + Z^2 + Z^3 + \cdots + Z^l) = Z(I - Z)^{-1}$

Step 6: Draw a causal diagram and analyze the results accordingly

$\{(D + R)\}$ is the horizontal axis, $\{(D - R)\}$ is the vertical axis, and then draw a causal diagram and analyze

4. Empirical research

4.1. The background introduction of case company

Haier Company, as the top 10 home appliance enterprise in China's green enterprise management, far exceeds the basic level of the same industry in the indicators of green supplier management, and has strict selection standards for green supplier. As a green supplier of Haier, Baosteel Group must have the green competition factors what the other competitive enterprises lack.

Baosteel group is the world's leading modern steel joint enterprise, strictly abides by the national environmental protection laws, regulations and standards, fulfills international environmental conventions, adheres to green manufacturing, and takes the road of sustainable development. In terms of environmental protection and resource utilization, Baosteel has independently studied the international advanced technology of high-efficiency heat transfer of coke oven riser tube (CATHE), and reduces the energy consumption of coke oven process by 6.9kgec/t. At the same time, it has independently developed the dioxin source treatment technology, which has the rate of dioxin emission reduction up to 92.2%. In addition, in cooperation with industrial scientific research institutions, it developed the flue integrated micro-dust electro coagulation technology and complete equipment technology, and PM2.5 decreased by 51.9%. And Baosteel uses artificial wetland system to
treat the wastewater, and the wastewater can be reused after treatment, thus achieves zero exclusion of this part.

In terms of green products, Baosteel group uses full lifecycle management to track products in an all-round way, and produces environmentally friendly products to reduce the consumption of downstream users and extend the service life. At the same time, the company produces products based on the principle of environmental protection, and controls the emission of toxic and hazardous substances, ensures the effective utilization of energy and resources, and adopts third-party enterprises for green certification in terms of use time, appearance and secondary recycling of product. At present, eight products of Baosteel group have been certified by Intertek Green Leaf Label.

4.2. The establishment of competitive factors facets and criterion
First, we should refer to the relevant literature on the competition factors of green suppliers at home and abroad, and formulate factors and facets. These documents include Zhu Qinghua and Geng Yong (2004) proposed 12 specific indicators in view of green procurement, such as the use and purchase of hazardous materials, the consideration of finished product recycling rate, and ISO14000 certification, etc. Tseng and Chi (2013) added green performance indicators when selecting green suppliers, including 12 environmental standards such as environmentally friendly design, total quality management, clean production, and internal green production design, etc. Based on the research results of green suppliers’ selection in recent years, Wang Xingxing (2007) summarized a comprehensive system of environmental performance measurement standards, which includes the following eight aspects: green image, pollution control, environmental management system, green design, green capacity, green products, green recycling, and pollution treatment costs.

Based on the above literature and combined with the research and analysis of green competitiveness factors of Baosteel group, the following are analyzed and discussed from three aspects of green quality, green products and green technology.

- Green Quality
  The green environment of the upstream supplier refers to the specific measures and policies implemented by the enterprise to reduce the environmental damage when the production and operation of the enterprises destroy the environment. Such as waste treatment, environmental management system, commitment to the protection of the social environment, production products in line with market and national environmental laws and regulations, etc.

- Green Products
  Green products refer to energy saving, pollution reduction and environmental protection and recycling of products in the production process. When choosing green products, manufacturers generally pay attention to the following aspects: product recycling and recycling rate, product use and maintenance cost, energy consumption of product production, green process flow, and product stability.

- Green Technology
  Green technology refers to the technology which can reduce environmental pollution and energy consumption. The commonly used technologies include: the use of environmentally friendly materials by enterprises, green process flow, non-toxic manufacturing process, and clean technologies.

4.3. Data acquisition, analysis and results
On the basis of referring to the relevant literature of this research, on November 1st, 2018, after communicating with the managers who had five years' experience in supply chain in Baosteel Company, the doctoral scholars in logistics management and the staff of Environmental Protection Bureau, we initially got the competitive factors related to green suppliers. On November 15th, 2018, we deeply communicated and discussed with the experts again, and finally determined the three major facets and 13 factors of the green supplier competitiveness factors (as shown in the following Table 1), and then determined the research framework of this research.
Table 1. The green supplier competitiveness factors

| Aspects            | Factors                         | Factor description                                                                 |
|--------------------|---------------------------------|------------------------------------------------------------------------------------|
| Green environment  | Waste treatment                 | The way in which supplier enterprises deal with waste discharge and the treatment effect |
|                    | Environmental management system | Environmental protection work plan and management system formulated by supplier companies for protecting the environment |
|                    | Enterprise social responsibility | Measuring the extent to which supplier enterprises meet environmental targets and the achievement of their commitment to protecting the social environment |
|                    | Environmental protection law     | Whether the raw materials and functions used by the supplier enterprises’ products comply with the market and relevant national environmental laws and regulations |
| Green products     | Material recycle and recycling rate | Recycling and recycling rate of materials from supplier enterprises |
|                    | Product use and maintenance cost | Products use and maintenance costs after purchasing products from supplier enterprises |
|                    | Energy consumption              | Various energy costs actually consumed by supplier enterprises in production activities |
|                    | Research and Development of green technology | The costs incurred by supplier enterprises in developing green technologies such as green packaging and green processes, etc. |
|                    | Product reliability             | The stability of availability and quality from supplier’s products over time |
| Green technology   | Environmentally friendly materials | The use technology of environmental protection material from supplier enterprises |
|                    | Green manufacturing process     | The use of green manufacturing processes of enterprises is mainly to study and adopt process schemes with less material and energy consumption, less waste, and less environmental pollution. |
|                    | Clear technology                | The costs of the treatment of environmental sanitation and using new energy equipment by supplier enterprises in treatment |
|                    | Non-toxic manufacturing process | Supplier companies use non-toxic processes and non-toxic materials in the manufacturing process |

The DEMATEL questionnaire was designed based on the above three facets and 13 factors. On November 20, 2018, experts were invited to fill out the questionnaire, and the questions and contents of the questionnaire were fully explained to answer the questions in the questionnaire, so as to ensure that the experts fully understood the questionnaire, and we obtained effective questionnaires.

After obtaining the expert evaluation results, the data is processed by the DEMATEL algorithm, and draw a causal diagram accordingly.

According to the above figure, the factors in the first quadrant include green manufacturing process, environment-friendly materials, clean technology, research and development of green technology, non-toxic manufacturing process, environmental protection law, and enterprise social responsibility. Among them, green manufacturing processes and environmentally friendly materials are factors that
are highly important and have a large impact on other factors, so they can be defined as key factors. The factor in the second quadrant is only energy consumption, which is the least important factor, and has a supplementary influence on the selection of green suppliers. The factors in the third quadrant include product reliability and product use and maintenance cost, which are low important but not easy to be affected, and are called independent factors. The factors in the fourth quadrant include material recycling and recycling rate, environmental management system, and waste disposal, which are low important and easy to be affected.

![Causal map](image)

**Figure 1. Causal map**

4.4. **Practical implications**

Observing Figure 1, it can be seen that green manufacturing process and environmentally-friendly materials are the key factors for core enterprises in the supply chain to choose green suppliers. In the process of production and operation, supplier enterprises not only need non-toxic and harmless raw materials, but pay attention to the auxiliary manufacturing process in the green manufacturing process also should meet the relevant regulations on environmental protection. For example, in the second quarter of the Children's Toys Products Quality Report released by the China Baby and Toys Association in 2018, it was mentioned that 81.63% of China's exports to the EU were recalled, the reasons for the failure are as follows: benzene content exceeding the standard, small parts unqualified, heavy metal content exceeding the standard, etc. Therefore, it can be seen that whether the parts and semi-finished products provided by the upstream suppliers meet the market environmental protection regulations greatly affects whether the products can be accepted by the market. As a representative of green home appliance enterprises, Haier actively responds to the national enterprise environmental protection policy and pays high attention to the market environmental qualification rate of parts and components provided by upstream suppliers. Therefore, for upstream suppliers, the enterprise's green manufacturing process capacity and the use of environment-friendly materials are important ways for supplier enterprises to improve their "green competitiveness".

5. **Conclusion**

In this study, through in-depth interviews with experts and reference to a large number of literatures, the green supplier competition factors are summarized into three major facets and thirteen criteria, and
we study the causal relationship analysis of green suppliers’ competition factors accordingly. According to the analysis of the DEMATEL’s empirical results, the following conclusions are drawn:

1) Green manufacturing processes and environmentally-friendly materials are the most important factors for the competitiveness of green suppliers, for upstream manufacturers, green manufacturing processes and environmentally friendly materials are the first considerations for companies.

2) Product reliability, product use and maintenance cost, material recycle and recycling rate are the most easily affected by other factors.

3) Among the 13 factors, special attention should be paid to the environmental protection law, because its cause degree is much higher than the others, indicating that it has the greatest impact on other factors.

From the above conclusions, this paper proposes the following suggestions for the reference of relevant enterprises.

1) Green suppliers focus on the understanding of "green" and its application in production. When improving green competitiveness, green suppliers should add "green" standards based on traditional supplier selection criteria (quality, price, on-time delivery, etc.). Based on the research in this paper, it is suggested that green supplier enterprises can greatly improve product stability, increase product durability, reduce product recycling times, and improve product "green" quality by improving green manufacturing process capacity and utilization rate of environment-friendly materials, thus optimize their green competitiveness.

2) Under the background of market globalization, enterprises must abide by the environmental protection laws of different countries and regions if they want to have a bigger market. According to the research in this paper, the environmental protection law has far more influence on other factors than other factors. Therefore, it is suggested that enterprises actively comply with environmental protection laws and regulations, which is not only beneficial to the development of enterprises green culture and establishing the concepts of green management and green production, but also beneficial to developing the market and enhance the green competitiveness of enterprises.

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