Identifying Key Factors for Sustainable Manufacturing and Development

Review of Integrative Business & Economics Research

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ABSTRACT

With global awareness of sustainable development continuing to rise, stakeholders of all parties are concerned about companies revealing the substance of Sustainable Development Goals (SDGs). The standard for evaluating a company's success is no longer limited to the single indicator of financial performance but also includes the company's sustainability practices. In this paper we have adopted decision making trial and evaluation laboratory (DEMATEL) to identify the key factors affecting an enterprise's ability to achieve sustainable development. Based on a literature review, we have grouped 11 criteria for defining sustainable development into the following three categories: sustainable manufacturing, corporate performance, and external pressure. By evaluating the interrelationships among these criteria, we can determine the significance of each criterion and causality relative to the others. The results indicate that eco-design, laws and regulations, and waste management are the three most important factors influencing a company's ability to achieve sustainable development. Identifying causality between the criteria enables enterprises to develop or improve their environmental policies to achieve better corporate performance, strengthen their competitive advantages, and realize companies' sustainable development goals.

Keywords: Sustainable development; Sustainable manufacturing; Corporate performance; External pressures.

Received 18 September 2020 | Revised 22 December 2020 | Accepted 12 February 2021.

1. INTRODUCTION

A country's manufacturing industry is a key determinant of its economic growth. In Taiwan, the manufacturing industry's output accounted for 32.2% of gross domestic

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

product in 2018. However, a lack of environmental awareness and inefficient environmental policies are likely to result in environmental damage and energy depletion, which may reduce Taiwan's manufacturers' competitiveness. The awakening trend of environmental protection has driven the enterprise develop towards a sustainable manufacturing practices (SMPs), measures to mitigate the environmental harm those companies cause. Sustainable manufacturing practices are considered to be one of the key factors in improving the environment. However, there has been no commonly accepted definition. Until 2008, the US Department of Commerce officially defined sustainable manufacturing as "the creation of manufactured products that minimize negative environmental impacts, conserve energy, and natural resources, are safer for employees, communities, and consumers and are economically sound (Moldavska and Welo, 2017)." According to this definition, sustainable manufacturing must minimize the negative impact on the environment during the production process, while addressing social and economic problems that manufacturing causes.

Nambiar (2010) has explored the question of whether companies that adopt SMP achieve better product quality and higher market share. Rusinko (2007) also has shown that implementing SMP, such as pollution prevention or product management, improves an enterprise's environmental performance, reduces manufacturing costs, and enhances its corporate image. These findings are consistent with the concept of the triple bottom line, namely, pursuing sustainable development, corporations must strike a balance between profitability, the environment, and social equity (Elkington, 1998).

Zubir *et al*. (2012) demonstrated that SMPs enhanced the environmental performance of a Malaysian automotive company, as well as its economic and social performance has offered an evidence observed case. However, Gimenez *et al.* (2012) showed that implementing sustainable operations may improve a company's environmental and social performance, but such operations may also increase production costs and negatively affect a corporation's short-term economic performance. Hami *et al*. (2015) attempted to explain the correlation between sustainable manufacturing and economic performance through the concept of innovation performance. By sustainable manufacturing, a company can facilitate external integration and knowledge sharing with various stakeholders (e.g., suppliers and/or customers) to achieve product and process innovation, reduce costs, improve product quality, and enhance economic performance. This indicates that, for the manufacturing sector, developing and applying SMP is a critical issue, both in terms of the environment and corporate competitiveness in the global marketplace.

In terms of external pressures, which is another critical issue for manufactures toward SMP. Pressures from the government and the society regarding environment, motivate enterprises to change their organizational structure and their operational strategies to

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

adopt SMP, which contribute both improving their competitiveness and responding to external pressures. Zhu *et al*. (2007) has confirmed that external pressures (e.g., market laws and regulations for market and other factors) prompt companies to adopt green practices (e.g., clean production) to achieve better environmental performance.

Based on the above, this study aims to: (1) explore the causal relationship between sustainable manufacturing, corporate performance, and external pressures; and (2) identify the key factors that motivate a corporation to implement strategies aimed at achieving sustainable development. Thus, the key factors identified being introduced as singleness of purpose to pave the way for a more sustainable manufacturing practice.

2. LITERATURE REVIEW AND CRITERIA FRAMEWORK

According to research and current theories, sustainable manufacturing, corporate performance, and external pressures form the framework that enables an enterprise to achieve sustainable development. We have selected eleven criteria to define these three main dimensions for analysis, as shown in Table 1.

Table 1. Corporate Sustainable Development Criteria

Dimension	Criteria	Reference
Sustainable Manufacturing(S)	Eco-design(S1)	Lin (2013); Zsidisin and Siferd (2001)
	Process design(S2)	Abdul-Rashid *et al*. (2017)Rusinko (2007)
	Energy management (S3)	Vinodh and Joy (2012)
	Waste management(S4)	Gupta *et al*. (2015)
	Supply chain management (S5)	Chan *et al*. (2012)
Corporate performance(P)	Financial performance(P1)	Russell and Millar (2014); Narasimhan and Kim(2002)
	Environmental performance(P2)	Abdul-Rashid *et al*. (2017)
	Social performance (P3)	Abdul-Rashid *et al*. (2017), Yusuf *et al*. (2013)
	Innovation performance (P4)	Horbach . *et al*. (2012); Kemp and Arundel (1998)
External pressure(E)	Regulation (E1)	Lin (2013)
	The pressure from stakeholder(E2)	Freeman (2010)

2.1. *Sustainable Manufacturing*

Garetti and Taisch (2012) stated that sustainable manufacturing is the ability to intelligently use natural resources in manufacturing to fulfill economic, environmental, and societal objectives, including protecting the environment and improving the quality of life for a company's employees, customers, and community. A series of SMP can be derived from the concepts of sustainable development and sustainable manufacturing, involving the design, manufacture, distribution, and recycling of products and services, thereby forming a production system that can assist companies in improving the environment and realize sustainable development (Hami, 2015). This study defines the

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

concept of a sustainable manufacturing practice into five aspects: eco-design (life-cycle design), process design, energy management, waste management, and supply chain management.

2.1.1. Eco Design

Ecological Design can also be referred to as Sustainable design, green design, or life cycle design (LCD), which refers to products or services designed with considerable environmental awareness. (Lin, 2013) The eco-design principles are aiming to reduce resource consumption and minimize waste generation by implementing a systematic measure of environmental risks (Zsidisin and Siferd, 2001). Echoing the environmental awareness, company should develop an applicable environmental strategy (e.g. LCD) to effectively promote sustainable development (Keoleian *et al*.,1994). LCD is a systematic approach to integrating environmental issues into design and selecting appropriate strategies to meet cost, quality, regulatory, and other requirements.

2.1.2. Process Design

Process design can decrease energy consumption and waste emissions throughout the production process and lead to more efficient use of resources to optimize production processes (Abdul-Rashid *et al*., 2017; Rusinko, 2007; Russell and Millar, 2014). In addition, cautious process design can also reduce the production costs and impact of toxic waste on the environment, thereby achieving better manufacturing flexibility and product quality (Jayal *et al*., 2010; Schönsleben, 2007). In practice, manufacturing industry can adopt strategy in terms of manufacture process, such as the "Lean Production" to strengthen the company's competitiveness. King and Lenox (2001) confirmed that the positive correlation between lean manufacturing and environmental performance, giving that lean manufacturing benefit the reduction of the marginal cost of pollution, which effectively strengthen the company's environmental performance.

2.1.3. Energy Management

Due to the negative environmental impacts of the fossil fuels, energy management becomes more important than ever. Adapting energy management approaches can reduce energy consumption, by using low-carbon technologies and reducing dependence on energy suppliers, thereby reaching the goal of sustainable development. (Vinodh and Joy, 2012) As climate change intensifies, companies are facing the impact of external pressures such as regulations of reducing the carbon footprint and carbon emission. Furthermore, the expanding energy demand of developing countries has caused the increases of the energy costs, leading to energy shortage as a current crucial issue to be addressed. Nevertheless, the environmental and economic factors mentioned above also provide impetus for the manufacturing industry to take substantive practices to reduce greenhouse gas emissions and energy consumption. (Fang *et al*., 2011).

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

2.1.4. Waste Management

Waste management refers to reducing the consumption of resources at the end of product life through reuse, remanufacturing, and recycling of materials and components. The purpose is to retain or re-grant the value of the products and materials. (Abdul-Rashid *et al*., 2017) As waste management is already an important business for many manufacturers, Srivastava (2007) indicates that waste management such as recycling and remanufacturing may be driven by regulations and economic factors. Decomposing and reusing products can help companies to reduce manufacturing costs and create additional economic value, especially in Asian countries (Khor *et al*., 2013).

Gupta *et al*. (2015) confirm that waste management and reduction techniques, such as reuse and recycling, are being incorporated into the manufacturing sector for three main reasons: (1) hidden economic value of waste, (2) market requirements, and (3) governmental regulations. The current trend is expected to minimize waste disposal and increase material reuse throughout the manufacturing life cycle. Joseph (2006) mentioned that the request of relevant stakeholders include government and non-government is an important factor for companies to engage in sustainable waste management.

2.1.5. Supply Chain Management(SCM)

Supply chain management (SCM) is the management of the flow of goods and services, involves the movement and storage of raw materials, of work-in-process inventory, and of finished goods as well as end to end order fulfillment from point of origin to point of consumption(Raymond Kelly,2019).The purpose of SCM is to reduce production costs, improve quality, and accelerate product innovation by communicating regularly and effectively with suppliers. Environmental issues have been a growing concern in SCM. Manufacturers have begun to incorporate green practices into SCM to meet goals associated with environmental and social practices. Chan *et al*. (2012) indicate that adopting green Supply chain management can improve company performance, strengthen corporate competitiveness, and response to stakeholders' request of environmental protection. In which perspectives are in line with Carter *et al*. (2002)'s finding that enterprises are under pressure from stakeholders, such as non-governmental organizations, which require companies to integrate social and environmental issues into the supply chain management.

2.2. Corporate performance

Ever since the core value of sustainability is highlighted globally, corporate performance indicators have changed from those focused-on economics or profitability to toward sustainability criteria, i.e., those that reflect performance in terms of economic, environmental and social goals (Pornpan Damrongsukniwat ,2019; Abdul-Rashid *et al*., 2017; Elkington, 1998).

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

In order to instant respond to sustainable trends, this study defines corporate performance into four categories: This study defines corporate performance into four categories: financial performance, environmental performance, social performance and (eco-) innovation performance.

2.2.1. Financial performance

Financial performance refers to a company's ability to earn profits and achieve market goals. It shows how a company to generate a profit maximization objective to its shareholders. (Russell and Millar, 2014). It is measured by market and financial criteria, including net profits, return on assets (ROA), return on investments (ROI), sales, market share, and other factors according to previous studies. (Narasimhan and Kim, 2002; Yang *et al*., 2011) This paper adopts the four indicators: net profits, return on assets, return on investments and sales to measure financial performance.

2.2.2. Environmental performance

Environmental performance captures a company's ability to rely on efficient and clean renewable energy and resources to reduce emissions, solid waste and hazardous materials during the manufacturing process, and to decrease environmental damage. It is crucial that renewable resources be used at a rate that permits them to replenish themselves, preventing pollutants increase and over-utilization. (Abdul-Rashid *et al*., 2017; Green *et al*., 2012; Yusuf *et al*., 2013). Adopting environmental approach, such as waste management and sustainable product design, can enhance the company's environmental performance (Gimenez *et al*., 2012; Rao and Holt, 2005; Zhu *et al*., 2004). Wong *et al*. (2012) demonstrated that adopting the product and process-oriented green production methods, including the use of environmental technologies, controlling carbon emissions, arranging cleaner transportation methods, and implementing recycling systems to reduce environmental pollution, can promote the environmental awareness and strengthen enterprises Environmental performance.

2.2.3. Social Performance

Social performance refers to an enterprise's ability to improve and maintain the quality of life for its employees, customers and the community in which it operates, including corporate governance and labor rights issues, without neglecting environmental concerns (Abdul-Rashid *et al*., 2017; Yusuf *et al*., 2013).

Social sustainability can improve working conditions and positively affect the community by diminishing environmental damage caused by manufacturing, which accordingly enhances the reputation of the factory and creates a better social environment (Gimenez *et al*.,2012). Abdul-Rashid *et al*. (2017) confirmed that sustainable manufacturing practices have a positive impact on social performance. In terms of process design, the company can reduce the environmental damage caused by manufacturing

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

activities, thereby improving the quality of social life and protecting the next generation from the impact of resource scarcity.

2.2.4. Innovation Performance

Innovation performance is also known as eco-innovation performance which liaison with variety of related concepts. Kemp and Arundel (1998) indicates that eco-innovation Performance including technical innovation, organizational innovation and marketing innovation. Hami *et al*. (2015) confirmed that eco-innovation performance including organizational innovation, process innovation and product innovation. Adapting OECD Innovation Strategy (OECD, 2018), the Oslo Manual for measuring innovation defines four types of innovation: product innovation, process innovation, marketing innovation and organizational innovation. This paper defines eco-innovation performance into five main types according to essential characteristic mentioned: technological innovation, organizational innovation, marketing innovation, product innovation and process innovation.

2.3. External Pressure

In recent years, enterprises have been increasingly influenced by the pressure from governments and their communities regarding both environmental and social issues. Current measures of organizational competitiveness have changed from managing costs to sustainability. The influence of Corporate Social Responsibility (CSR) on corporate competitiveness will continue to grow in importance (Sarkis *et al*., 2010). Strong pressure from laws & regulations is one of the key factors influencing corporations to adopt sustainable manufacturing processes, urging them to implement green practices, such as green purchasing and recycling, to achieve better environmental performance (Zhu *et al*., 2007; Lin, 2013). According to previous studies, this paper divides external pressure into two parts, namely, regulatory pressure and stakeholders pressure.

2.3.1. Regulatory pressure

Regulatory pressure is mainly from international standards and domestic regulations. These regulations aiming to strengthen the environmental awareness of enterprises, resulting them to set up their priorities to adopt environmental-related strategies to meet the requirements of government laws and regulations from international organizations as well (Lo and Lai, 2020; Lin, 2013). Nowadays, the international community is playing a crucial leading role in terms of environmental issues giving that the environmental protection regulations and environmental awareness has a major impact on various industries, such as the Montreal Convention restricting chlorofluorocarbons (CFC) emissions 1987, the Tokyo Protocol 1997 hopes that countries would be able to reduce their carbon emissions and thereby maintain the stability of the ecosystems. The Paris Agreement in 2015 expected the world to work together to slow down the generation of

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

greenhouse gases and reduce the impact from global warming. In addition, the European Union adopted the Waste Electrical and Electronic Equipment Directive (WEEE) in 2003 to specify the recycling and recycling goals of all waste electronics and related equipment, and the Restriction of Hazardous Substances Directive (RoHS) mainly targeted at materials and technical specifications of electronic and electrical related products. It is expected that these regulations can restrain enterprises and reduce their impact on the environment (Chen *et al*., 2006). Taiwanese manufacturers play an important part of the international supply chain, it is essential to comply with relevant guidelines of the environmental protection laws and regulations in product design and production tests.

2.3.2. Stakeholders pressure

Freeman E. defines a stakeholder as 'any group or individual who can affect or is affected by the achievement of the organization's objectives'. If the company expects sustainable development, the company or organization must develop a strategy that can meet the requirements of various stakeholders (Freeman et. al, 2010).

Pressure from stakeholders is crucial to companies. A number of previous studies have confirmed that the pressure from stakeholders may motivate companies to adopt sustainability practices, and take more SMP or environmental practices, such as green product or process design and sustainable SCM to improve performances and obtain a competitive advantage (Meixell and Luoma, 2015; Wolf, 2014; Yu and Ramanathan, 2015). Stakeholders play an important role that causes most companies to adopt sustainable manufacturing practices, and those companies who adopt more environmental practices reveal more engagement in process and product innovation than companies that retard relevant practices and stakeholder pressure would impact positively on environmental performance. (Yu and Ramanathan, 2015; Theyel and Hofmann, 2012). Meixell and Luoma (2015) and Wolf (2014) indicate that the pressure exerted by stakeholders from the supply chain may lead companies toward a more sustainability awareness therefore to set the sustainability goals or adopt sustainability practices in response to those relevant stakeholder’s requirements.

3. RESEARCH METHODOLOGY

3.1. Decision making trial and evaluation laboratory (DEMATEL)

Decision making trial and evaluation laboratory (DEMATEL) is an effective tool for building and analyzing a structural model involving causal relationships between complex factors. DEMATEL technique was developed by the Geneva Research Centre of the Battelle Memorial Institute to visualize the structure of complicated causal relationships through matrixes. It deals with evaluating interdependent relationships among factors and finding the critical ones through a visual structural model. Due to the

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

merit and capabilities, DEMATEL has received high attention (Si S.L.et. al, 2018) and many researchers have employed it to resolve complicated system problems in various areas. The formulating steps of the classical DEMATEL can be summarized as follows:

Step 1 Generate the direct-influence matrix. To assess the relationships between n factors in a system, suppose that L experts in a decision group are asked to indicate the direct influence that factor i has on factor j, an integer score of 0, 1, 2, 3, and 4, representing "no influence", "low influence", "medium influence", "high influence" and "very high influence". These pairwise comparisons between any two factors are denoted by x_{ij}. Then, the individual direct-influence matrix $\mathrm{X}_k = \left[x_{ij}^k\right]_{n\times n}$ provided by the K^{th} expert can be formed, where all principal diagonal elements are equal to zero and x_{ij}^k represents the judgment of decision maker k on the degree to which factor i affects factor j. By aggregating the L experts' opinions, the group direct-influence matrix $\mathrm{X} = \left[x_{ij}\right]_{n\times n}$ can be obtained by

$$x_{ij} = \frac{1}{\mathrm{L}} \sum_{k=1}^{\mathrm{L}} x_{ij}^k \ , i\ , \ j = 1, 2, \ldots\ldots, n. \tag{1}$$

Step 2 *Calculate the normalized direct-influence matrix Z.*

Given that the sum of each row j of matrix X represents the total direct effects that factor i on the other factors, $\max\limits_{1\le i\le n} \sum_{j=1}^{n} x_{ij}$ represents the total direct effects of the factor with the most direct effects on others. Similarly, $\max\limits_{1\le j\le n} \sum_{i=1}^{n} x_{ij}$ represents the total direct effects received of the factor that receives the most direct effects from others.

$$\mathrm{S} = \max\left\{ \max_{1\le i\le n} \sum_{j=1}^{n} x_{ij} \, , \max_{1\le j\le n} \sum_{i=1}^{n} x_{ij} \right\} \tag{2}$$

$$\mathrm{Z} = \frac{\mathrm{X}}{\mathrm{S}} \tag{3}$$

Step 3 Establish the total-influence matrix T.

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

The total-influence matrix $\mathrm{T} = \lfloor t_{ij} \rfloor_{n \times n}$ is computed by summing the direct effects and all of the indirect effects by

$$\mathrm{T} = X + X^2 + X^3 + \ldots\ldots\ldots + X^h = X(I - X)^{-1}, \quad as \quad h \to \infty \qquad (4)$$

in which *I* is denoted as an identity matrix.

Step 4 Produce the influential relation map (IRM).

The vectors R and C, representing the sum of the rows and the sum of the columns from the total-influence matrix T, defined by the following formulas:

$$\mathrm{R} = [r_i]_{n \times 1} = \left[\sum_{j=1}^{n} t_{ij} \right]_{n \times 1} \qquad (5)$$

$$C = [c_j]_{1 \times n} = \left[\sum_{i=1}^{n} t_{ij} \right]'_{1 \times n} \qquad (6)$$

Where superscript ' denotes to transpose. r_i is the *i*th row sum in the matrix *T* and displays the sum of the direct and indirect effects depicting from factor *i* to the other factors. c_j is the *j*th column sum in the matrix T and dispatches the sum of direct and indirect effects that factor *j* is receiving from the other factors. When *j* = *i*, the sum $(r_i + c_i)$ provide an index of the strength of influences given and received by factor i. That is, $(r_i + c_i)$ stands for the degree of central role that the factor plays in the system. In addition, the difference $(r_i - c_i)$ shows the net effect that factor *i* contributes to the system. When $(r_i - c_i)$ is positive, factor *i* is a net influencer and should be grouped into cause group, and when $(r_i - c_i)$ is negative, factor *i* is a net receiver, and should be grouped into effect group. The average matrix $\mathrm{X}_k = \lfloor x_{ij} \rfloor_{n \times n}$ is also called the initial direct relation matrix.

*Step 5 S*et a threshold value to draw the IRM

In some situations, the IRM will be too complex to show the valuable information for decision making if all the relations are considered. Therefore, a threshold value α was computed by the average of the elements in matrix T, as computed by equation (7). Where N is the total number of elements in matrix T. This process aimed to eliminate some minor effects elements in matrix T. That is, only the element of matrix *T*, whose influence level is greater than the value of α, would be selected and shown in IRM.

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j-1}^{n} t_{ij}}{N} \qquad (7)$$

Step 6 Divide the IRM into four quadrants

ISSN: 2304-1013 (Online); 2304-1269 (CDROM); 2414-6722 (Print)

IRM is divided into four quadrants I to IV, by calculating the mean of $r+c$, as displayed in Figure 1. If the value of $r+c$ is larger than the mean of $r+c$, and with *r-c* value above zero, then the factor falls in quadrant I. The factors in quadrant I are identified as core factors since they have high prominence and relation. The factors in quadrant II are those with $r+c$ values smaller than the mean of $r+c$, and *r-c* values are above zero. As such, these factors are identified as driving factors because they have low prominence but high relation. The factors in quadrant III are relatively disconnected from the system (called independent factors) as they have low prominence and relation. The factors in quadrant IV are those with $r+c$ values larger than the mean of $r+c$, and *r-c* values are below zero. Hence, these factors are identified as impact factors or intertwined receivers as they have high prominence but low relation, which are influenced by other factors and cannot be improved directly.

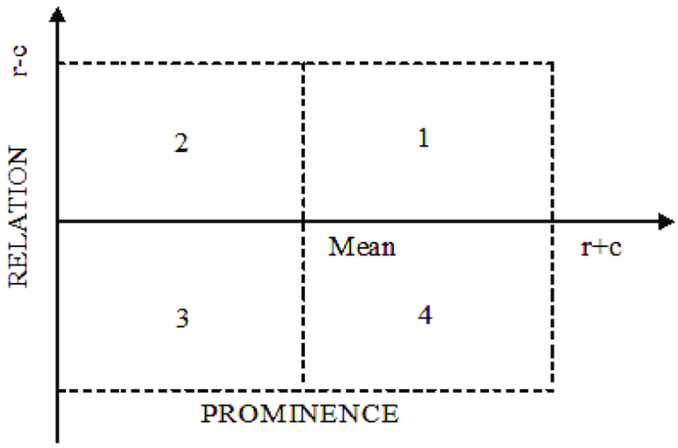

Figure 1 Four-quadrant IRM structure

4. ANALYSIS AND DISCUSSION

In the interviews, Teng suggested that 5 to 15 expert questionnaires are required (Teng, 2002). Nevertheless, Saaty and Vargas (Saaty and Vargas, 1994) assumed that it is appropriate to have 3 to 7 expert questionnaires since expert questionnaires are adopted as an expert's judgment rather than statistical concepts (Lee *et al*., 2012). In this study, eleven experts selected were invited from industry with experience in the manufacturing industry in Taiwan. The backgrounds of the experts are shown in Table 2.

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Table 2 The Respondent Enterprise Profiles

No.	Founded time	Fixed Assets(NTD) (10 Thousand)	Industry
1	More than 10 years	Less than 1000	Food Manufacturing
2	More than 10 years	More than 3000	Textiles Mills
3	More than 10 years	2000-2999	
4	2-5 years	Less than 1000	Electronic Parts and Components Manufacturing
5	More than 10 years	500-999	Motor Vehicle Parts Manufacturing
6	More than 10 years	More than 3000	Chemical Material Manufacturing
7	2-5 years	Less than 1000	Machinery and Equipment Manufacturing
8	More than 10 years	More than 3000	
9	More than 10 years	1000-1999	Metalworking Manufacturing
10	More than 10 years	Less than 1000	
11	2-5 years	More than 3000	

In the first step, we used equation (1) to calculate the average matrix from 11 expert questionnaires. The next step is to calculate the normalized direct-influence matrix by equations (2) and (3) and then equation (4) was used to establish the total-influence matrix T. The results were shown in Table 3 and Table 4. The last step is to build the influential relation map (IRM), a threshold value (α) was computed by equation (7).

The value r and value c of each criterion in the matrix T were calculated by equations 5 and 6. The sum $\left(r_i + c_i\right)$ gives an index representing the total effects both given and received by the *i*th factor. In addition, the difference $\left(r_i - c_i\right)$ gives an index indicating the net effect the *i*th factor contributing to the system, which were shown in Table 6. Based on the degree of influence in Table 6, waste management (S4), regulation (E1) and process design (S2) are the three most important criteria with the values of 10.322, 9.977, and 9.933, respectively. They have high prominence and relation and are highly connected to other criteria. Supply chain management (S5), social performance (P3), and innovation performance (P4) are the three least important criteria, with the values of 7.800, 7.734 and 7.431, respectively. As stated in the relation, the pressures from stakeholders (E2), eco-design (S1), regulations (E1), innovation performance (P4), waste management (S4) and energy management (P3) are net causers, which can influence all or part of the criteria. Conversely, financial performance (P1), environmental performance (P2), social performance (P3), process design (S2) and supply chain management (S5) are net receivers and are always influenced by all or part of the criteria.

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Table 3. The Direct-Influence Matrix

	S1	S2	S3	S4	S5	P1	P2	P3	P4	E1	E2
S	0	2.72	2.09	3.00	1.90	2.36	2.72	2.63	2.09	2.72	1.63
S	2.18	0	2.45	2.54	2.09	2.45	2.45	1.81	2.00	2.36	1.36
S	2.00	2.54	0	2.27	1.72	2.18	2.36	2.18	1.90	2.63	1.54
S	3.00	2.72	2.72	0	2.18	2.18	3	2.54	1.36	3.09	1.45
S	1.63	2.09	1.36	1.81	0	2.27	1.81	1.72	1.18	1.45	1.36
P	1.54	2.36	1.54	1.72	2.00	0	1.45	1.27	1.63	1.54	2.09
P	2.36	2.18	1.81	2.72	1.45	1.45	0	1.45	1.09	2.54	1.27
P	1.54	1.63	1.63	2.18	1.45	1.27	1.72	0	1.18	1.81	1.27
P	2.09	2.18	1.72	1.54	1.54	1.90	1.63	1.36	0	1.36	2.00
E	2.63	2.90	2.54	3.18	1.90	1.81	2.72	2.27	1.54	0	2.00
E	1.63	2.45	2.18	1.81	2.27	2.72	1.90	1.54	2.09	2.18	0

Table 4. Total Influence Matri T

	S1	S2	S3	S4	S5	P1	P2	P3	P4	E1	E2
S	0.40	0.55	0.47	0.55	0.43	0.48	0.52	0.46	0.39	0.52	0.37
S	0.45	0.42	0.45	0.50	0.40	0.45	0.48	0.40	0.36	0.47	0.34
S	0.44	0.50	0.35	0.48	0.39	0.43	0.47	0.41	0.35	0.48	0.34
S	0.52	0.56	0.50	0.45	0.45	0.48	0.54	0.47	0.37	0.54	0.37
S	0.35	0.40	0.33	0.38	0.25	0.36	0.37	0.32	0.27	0.35	0.27
P	0.35	0.42	0.34	0.39	0.34	0.29	0.36	0.32	0.29	0.37	0.30
P	0.41	0.44	0.38	0.45	0.34	0.37	0.34	0.35	0.29	0.43	0.30
P	0.33	0.37	0.33	0.38	0.30	0.32	0.35	0.25	0.26	0.36	0.26
P	0.37	0.42	0.35	0.38	0.32	0.36	0.37	0.32	0.23	0.36	0.30
E	0.50	0.56	0.48	0.56	0.43	0.46	0.52	0.45	0.37	0.42	0.38
E	0.41	0.49	0.42	0.45	0.40	0.44	0.44	0.38	0.35	0.45	0.27

To build influential relation map (IRP), a threshold value (α=0.4028) was computed and the value of t_{ij} greater than α in matrix T were main criteria and shown in Table 5. The IRM shown in Figure 2 indicates that regulation (E1), eco-design (S1) and waste management (S4), are not only three key factors that affect companies' ability to achieve sustainable development but the core issues that companies tend to address. The results indicate that enterprises should value more the impact of external pressure from laws and

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regulations and should position eco-design and waste management at the core of corporate governance to achieve sustainability. The finding results of this study can provide management with information to better understand these causal relationships and to assist companies in improving their SMP strategies.

Table 5. Total Influence Matrix For Main Factors

	S1	S2	S3	S4	S5	P1	P2	P3	P4	E1	E2
S	0.40	0.55	0.47	0.55	0.43	0.48	0.52	0.46	0.39	0.52	0
S	0.45	0.42	0.45	0.50	0.40	0.45	0.48	0.40	0.36	0.47	0
S	0.44	0.50	0	0.48	0	0.43	0.47	0.41	0.35	0.48	0
S	0.52	0.56	0.50	0.45	0.45	0.48	0.54	0.47	0.37	0.54	0
S	0	0.40	0	0	0	0	0	0	0	0	0
P	0	0.42	0	0	0	0	0	0	0	0	0
P	0.41	0.44	0	0.45	0	0	0	0	0	0.43	0
P	0	0	0	0	0	0	0	0	0	0	0
P	0	0.42	0	0	0	0	0	0	0	0	0
E	0.50	0.56	0.48	0.56	0.43	0.46	0.52	0.45	0	0.42	0
E	0.41	0.49	0.42	0.45	0	0.44	0.44	0	0	0.45	0

threshold value (α=0.4028)

It is also worthwhile to discuss process design (S2) and environmental performance (P2), which are considered to be core issues for companies in achieving sustainable development. Nevertheless, companies do not need to address them directly. Causal relationships show that these two criteria (in quadrant IV) are influenced by other criteria. Therefore, manufacturers can improve process design and environmental performance by managing the factors in quadrant I and II, which may facilitate effective allocation of company resources.

Sustainability is nowadays a wide research field because of the urgency of reducing environmental loadings of industrial production. Many companies have already started to take important steps towards sustainable manufacturing. However, a lot of small and medium-sized businesses (SMEs), that account for approximately 99% of all enterprises in Taiwan, have not yet embraced this great tendency. They may be struggling with their short-term survival, or cost pressure from clients, or lack of knowledge and resources to invest in environmental improvement, or simply not know where to start. It is important to put forward key guidelines as the reference for Taiwan SMEs to practice sustainable

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manufacturing.

Table 6. The Degree of Influence

Criteria	r	c	r+c	r-c	Group
Eco-design(S1)	5.2008 (2)	4.5706 (5)	9.7714 (4)	0.6303 (2)	Cause
Process design(S2)	4.7572 (4)	5.1753 (1)	9.9326 (3)	-0.4181 (8)	Affected
Energy management(S3)	4.6871 (5)	4.4491 (7)	9.1362 (5)	0.2380 (6)	Cause
Waste management(S4)	5.2989 (1)	5.0228 (2)	10.3220 (1)	0.2761 (5)	Cause
Supply chain management(S5)	3.7037 (10)	4.0963 (9)	7.8000 (9)	-0.3926 (7)	Affected
Financial performance(P1)	3.8159 (9)	4.5031 (6)	8.3190 (7)	-0.6872 (11)	Affected
Environmental performance(P2)	4.1637 (7)	4.8190 (3)	8.9828 (6)	-0.6553 (10)	Affected
Social performance(P3)	3.5467(11)	4.1875 (8)	7.7342 (10)	-0.6408 (9)	Affected
Innovation performance(P4)	3.8585 (8)	3.5722 (10)	7.4307 (11)	0.2862 (4)	Cause
Regulation(E1)	5.1753 (3)	4.8018 (4)	9.9771 (2)	0.3735 (3)	Cause
Stakeholders(E2)	4.5355 (6)	3.5456 (11)	8.0811 (8)	0.9899 (1)	Cause
		Average	8.8625		

*Numbers in parentheses are rankings.

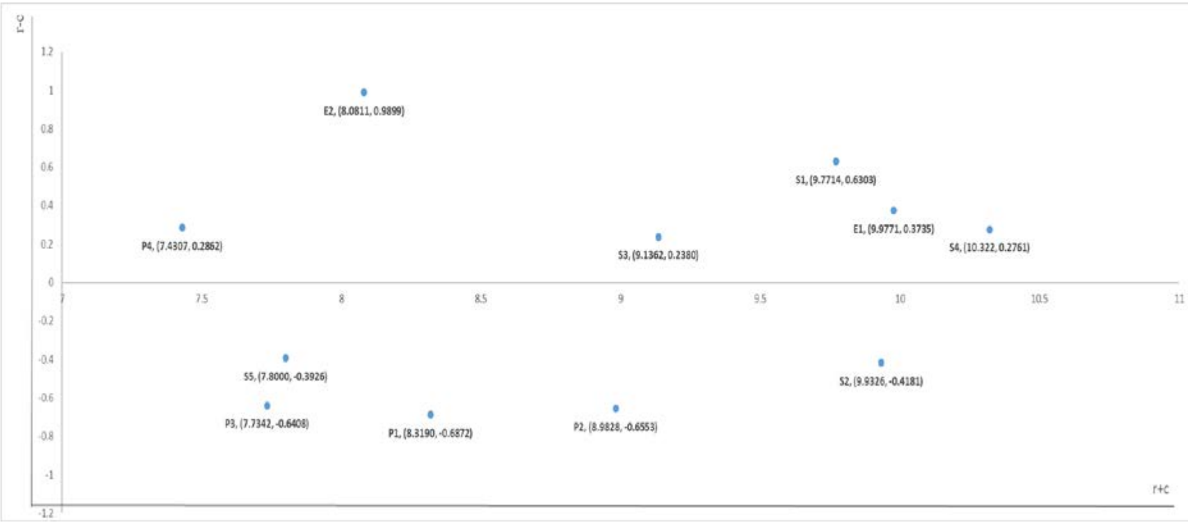

Figure 2 The Influence Relationship Map of the Main Criteria

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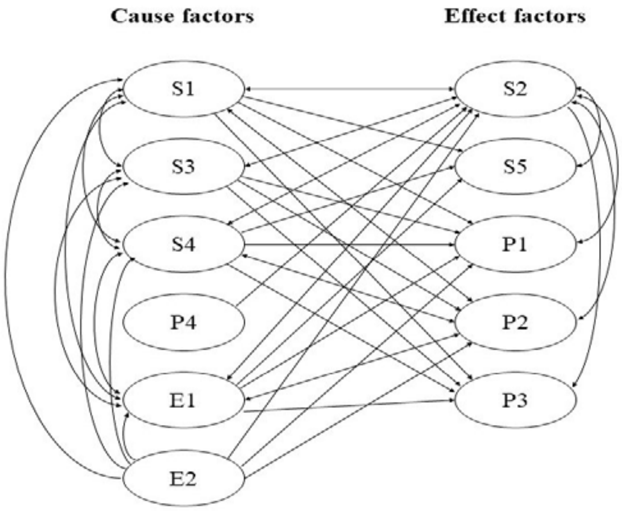

Figure 3 The Cause-Effect Relationship of the Main Criteria

5. CONCLUSION

In this paper we have adopted DEMATEL to identify the key factors affecting an enterprise's ability to achieve sustainable manufacturing. This study finds that eco-design, laws and regulations, and waste management are three of the most important criteria motivating manufacturers to achieve sustainable development. Thus, to best take advantage of opportunities, manufacturers should observe government regulations and international standards and comply with regulatory restrictions. According to the causal relationships diagram, enterprises have better given priority to issues such as eco-design and waste management. In terms of eco-design, companies can make their efforts in designing the product and service according to both the environmentally conscious and customer driven, aiming at minimizing energy loss and the waste of resources in the process of product manufacturing or output, thereby becoming more innovative and more adept at identifying cost-effective alternatives. Regarding waste management, enterprises can improve performance and meet social responsibility goals by recycling, reusing, and remanufacturing to breathe new life into used products and reduce landfill use.

The "environmental performance" and the "process design" of sustainable manufacturing aspects are also considered as the company's core projects. However, instead of focusing directly on these two criteria, this study recommends that companies enhance the other aspects such as energy management, waste management, etc., in resulting effectively the improvement of the environmental performance or process design.

This research contributes to construct a new evaluation framework that incorporates

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three major dimensions of sustainable manufacturing, company performance and external pressure, and its 11 criteria into the evaluation framework. Second, we use DEMATEL model to analysis for decision making, giving that DEMATEL can handle complex structures. The findings will help small and medium-sized enterprises to reach effective resource allocation by concentrating their resources on key factors and benefiting the other factors through causality result as well.

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