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Analysis model of the sustainability development of manufacturing small and medium- sized enterprises in Taiwan

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ABSTRACT

To maintain competitiveness in the marketplace, enterprises have considered sustainability development as an important goal and initiated numerous strategies for sustainability. The three main dimensions, namely, economic, social and environmental aspects, have become the focus of the sustainable development of enterprises while serving as vital indicators for enhancing competitiveness. However, prior studies on sustainable development primarily emphasised theoretical discussions, and few scholars have conducted quantitative data analysis, especially in the small and medium-sized enterprises (SMEs) area. Given this research gap, this study developed an integrated multi-attribute decision analysis model to evaluate the sustainability development of manufacturing SMEs in Taiwan. The present research identifies key sustainability indicators that play a vital role in boosting the sustainable performance of manufacturing SMEs.

1. Introduction

With the advancement of science and technology, the demand for high quality of life has increased gradually, resulting in considerable usage of resources for production and consumption. However, the intensive use of resources has triggered adverse effects on the environment, causing climate change, which is considered the greatest danger to the world (Dincer and Rosen, 1999; Goldemberg, 2006). As cited in Broman and Robèrt (2017), Steffen et al. (2015) indicated that if humans continued to disregard the damages to ecosystems and increase the risk to the biosphere, then human civilization will be seriously affected. Trianni et al. (2017) highlighted the need to improve the sustainability of manufacturing sector because existing production models presents a non-sustainable development trend; hence, technology, management, organisation, and behavior of the production system require adjustment and change (Blok et al., 2015). Mazzarol et al. (1999) emphasised that small and medium-sized enterprises (SMEs) play a key role in national economic development. Hillary (2004) estimated that SMEs can be responsible for up to 70% of all pollution worldwide. Determining the appropriate management system to ensure sustainable development is an important issue for SMEs, not only because of pressure from stakeholders but also from the enterprise development perspective of the supply chain management (Burke and Gaughran, 2007). SMEs require an appropriate management method and a practical framework for the identification and implementation of sustainable development plans.

Moore and Manring (2009) also pointed out that many factors have gradually led SMEs to take the initiative in introducing sustainable development practices. Given the characteristics of SMEs, their sustainable development strategies, such as personalized management, lack of funds, resource constraints, flexibility, horizontal structure, small number and concentration of customers, narrow market, and lack of expertise, are different from that of large enterprises (Alshawi et al., 2011; Ciliberti et al., 2011). SMEs should develop practical implementation knowledge or establish management tools for sustainability (Burke and Gaughran, 2007).

Promoting SME participation in sustainable development (SD) becomes an inevitable strategy. Loucks et al. (2010) revealed that SMEs tend to take a passive view of sustainable development, and pay little attention to examining their impact on the environment. This tendency causes the implementation of sustainable development in SMEs to be considered as slower than that in large enterprises. Unlike large corporations, SMEs often lack financial resources, time, personnel, technological expertise and the

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organisational structure for implementing sustainable development (Nicholas et al., 2011; Schulz et al., 2011). Moreover, they generally have less knowledge on the environmental impact of SMEs and do not comprehend fully the benefits of sustainable development and the tools for developing sustainability strategies and practices (Aykol and Leonidou, 2015; Lawrence et al., 2006). Perrini et al. (2007) also noted that SMEs had difficulty participating in sustainable development.

According to Shields and Shelleman (2015), many companies have become increasingly concerned with the sustainability of their efforts and have also gradually recognised the potential benefits of sustainability reporting. Sustainability development has been acknowledged as a competitive strategy of enterprises (Ciasullo and Troisi, 2013; Schaltegger, 2011; Conway, 2014). Severo et al. (2017) stated that SD may provide a competitive advantage over competitors (Bhupendraa and Sangleb, 2016; Lukena et al., 2016). The benefits of sustainable development efforts are reflected not only in quantifiable financial performances and other economic indicators (Conway, 2014; Brammer et al., 2012) but also in many managerial ways. Hsu et al. (2017) mentioned that sustainable development improves corporate reputation (Lee, 2012), obtains legality of management decisions (Hart and Milstein, 2003), promotes labor relations, attracts resources, and reduces the pressure of stakeholders to the enterprise (Hardjono and Marrewijk, 2001).

However, many SMEs may be unaware of these benefits (Lawrence et al., 2006). Given their lack of financial support, related knowledge background and human resources, SMEs are relatively less concerned with environmental impacts. As a result, major companies and governments have focused their attention on sustainability development for SMEs (Jenkins, 2009), because many SMEs act as supply chain partners for large companies.

Given the abovementioned role of SMEs, manufacturing SMEs are then the sector that requires sustainability improvement. Considering the relatively scarce resources of SMEs, academia should provide practical research on the method that can be implemented and identify key strategic factors that can be used to produce the greatest leverage of sustainability development for SMEs.

Based on the literature review, triple bottom line (TBL) performance indicators are developed in this study, which cover influencing factors on sustainability development. Then, sustainability performance indicators are selected using Fuzzy Delphi Method (FDM). The TBL performance indicators are constructed such that they can describe and evaluate the effectiveness of performing sustainability development. Furthermore, grey relational theory (GRA) and neighbourhood rough set theory (RST) are used to assess the implementation of sustainability development for SMEs. Finally, sensitivity analysis is employed to observe the change in the variables, thereby facilitating the exploration of critical factors that affect performance.

The remainder of this research is organised as follows. Section 2 identifies the sustainability development factors suggested in the literature and surveys related work on the fuzzy Delphi method (FDM), the grey relational analysis (GRA), and neighbourhood rough set theory (RST). Section 3 depicts the detailed approaches applied in this study, including FDM, GRA and RST. Section 4 demonstrates a case implementation. Finally, Section 5 discusses the conclusions of our findings.

2. Literature review

2.1. Sustainability development

Sustainability development has been defined as the ability to meet human needs without compromising the needs of future generations (Brundtland Commission, 1987). In recent years, growing concern for the protection of the environment has led to the recognition of sustainability development as one of the most important goals, and attention has been paid to the operations management of enterprises, which has resulted in a extremely broad scope of the surveyed industry.

Liu et al. (2011) assessed the sustainable fisheries development in offshore and coastal fisheries in Taiwan and confirmed their potential problems, including employee numbers, incorrect statistical data and unacceptable institutional expense. Abdulrazak and Ahmad (2014) highlighted the attention to sustainable development in Malaysia, especially on the implementation of corporate social responsibility (CSR). Their paper introduced and discussed the viability of prominent CSR theories. Their conclusion is helpful for establishing sustainable development in Malaysia and facilitates the identification of a more appropriate CSR practice and program. On the basis of the sustainable development of agriculture in India, Chand et al. (2015) used the three dimensions of economy, society and ecology to identify the weak indicators of sustainability development that must be strengthened. Omri et al. (2015) addressed several issues related to the economic, social and environmental dimensions of mass production and fuel consumption. The solar energy case in Tunisia proved the significant effects of sustainable development on the three dimensions of economy, society, and ecology.

Focusing on the sustainable development of clean production, Khalili et al. (2015) suggested that higher education leaders should assess the necessity and urgency of design training programs to assist in the development of human capital for supporting sustainable development. Inclusion of the resource management theme in academic curricula is the foremost strategy, followed by the development of human capital, human system design, and sustainable economic development and prosperity. Sánchez (2015) established a framework for the impact of sustainability on the organisation to ensure it undertakes the right projects to meet its business strategy and stakeholder needs. Hsu et al. (2017) proposed a balanced scorecard (BSC) approach to ascertain the priority of sustainability development based on the limited resources of SMEs.

Different scholars, research areas and perspectives have generated various points of view, and these perspectives represent a wide range of variations. Omri et al. (2015) pointed out that literature on sustainable development has been growing continuously in recent years. Despite the abundance of literature and issues related to sustainable development, much controversy remains regarding this ambiguous and multifaceted concept, which makes the description of the concept of sustainable development by using a consistent and operational content extremely challenging. Osofsky (2003) attempted to explain the reasons for the vague concept of the term and emphasised that no unique, universally accepted definition of sustainability development exists (Munasinghe, 2001; Sedlacko and Gjoksi, 2009). Nevertheless, at least one consensus has been widely accepted by scholars, that is that the main dimensions of sustainable development include environmental, social and economic sustainability (Dyllick and Hockerts, 2002; Omri et al., 2015; Hsu et al., 2017; Thabrew et al., 2018; Aguiñaga et al., 2018).

Shields and Shelleman (2015) revealed that because of the growing attention devoted to sustainability development, SMEs face a potentially significant change in their operating environment and substantial impact on their strategic thinking. Bonn and Fisher (2011) suggested that to achieve sustainability in an organisation, managers must combine different factors and varied sustainability measures into their strategic decision-making process. Accordingly, such action will enable a company to identify opportunities for strategic improvements in sustainability.

2.2. Sustainability index

On the basis of the triple bottom line approach, this study provides an extensive literature review and determines the practical quantitative indicators proposed in the literature as sustainability performance assessment factors for practical data collection. The TBL approach has been widely accepted to define the basic dimensions of sustainable development (e.g., Callens and Tyteca, 1999; Tanguay et al., 2010; Hsu et al., 2017; Aguiñaga et al., 2018). Three dimensions, namely, economic, social and environment, have been proposed as criteria in the literature.

2.2.1. Economic dimension

The economic dimension includes the general activities of production, distribution, delivery and consumption. These items are vital important performance indicators for enterprises, including various costs and R&D and design capabilities. According to the literature, we sum up the following items for economic aspects:

1. Production cost: Including manufacturing, maintenance and repair costs (Lee and Saen, 2012; Erol et al., 2011);
2. Ordering costs: The sum of unit variable and fixed ordering costs (Lee and Saen, 2012; Erol et al., 2011);
3. Logistics costs: The sum of unit variance and distribution variance transportation costs (Lee and Saen, 2012; Erol et al., 2011);
4. On-time delivery: The ability to deliver according to the schedule (Lee and Saen, 2012; Erol et al., 2011);
5. Quality assurance: Quality assurance achievements, such as certificates (Lee and Saen, 2012; Erol et al., 2011);
6. Rejection rate: The amount of rejected raw material detected by quality control (Lee and Saen, 2012; Erol et al., 2011);
7. Technology Level: Supplier's technology development to meet current and future needs of the company (Lee and Saen, 2012; Erol et al., 2011);
8. R&D Capability: Supplier's R&D capability to meet current and future needs of the company (Lee and Saen, 2012; Erol et al., 2011);
9. Design capabilities: Supplier's ability to design new products to meet current and future needs (Lee and Saen, 2012; Erol et al., 2011);
10. Governance: The company recognizes the responsibility of accepting entrustment, and the board of directors and management focus on the interests of all corporate stakeholders (Lee and Saen, 2012);
11 Corporate transparency and accountability: The company provides timely information on its products, services and activities and supplies instantaneous information on sustainability performance activities (Lee and Saen, 2012);
12. Number of shareholders (Erol et al., 2011);
13. Profits: Profit indicators are measured from the yields earned by the organisation (Erol et al., 2011); and
14. Investment: The investment indicator is employed to calculate the impact of general investment and environmental investment, which measures the healthy development of economic organisations collectively (Erol et al., 2011).

2.2.2. Social dimension

Social dimension refers to the scope of human activities or the settlement. The impact of enterprises on the sustainable development of society includes the number of job vacancies released in the local area, work safety and the protection of community surroundings during the production process. These effects will have a significant effect on the image of the enterprise. According to the literature, we summarise the following indicators for the social dimension:

1. Increase in local community employment opportunities (Govindan et al., 2013);
2. Green image: The proportion of green suppliers to total suppliers (Erol et al., 2011; Hong and Andersen, 2011; Lee et al., 2012);
3. Managers' commitment to green supply chain management: Commitment and support from high-level managers to improve green supply chain management practices and environmental performance (Erol et al., 2011; Hong and Andersen, 2011; Lee et al., 2012);
4. Employee environmental training: Environmentally oriented training of staff (Erol et al., 2011; Hong and Andersen, 2011; Lee et al., 2012);
5. Employment practices: disciplinary and security practices, employee contracts, labour sources, diversity, discrimination, flexible work arrangements, employment opportunities, employment compensation and career development (Tseng, 2013);
6. Health and safety: including health and safety accidents and health and safety practices (Tseng, 2013);
7. Impacts on local communities: health, education, services, infrastructure, housing, health and safety events, regulatory and public services, supporting educational institutions, security, cultural attributes, economic welfare and growth, and grants and donations to support community projects (Govindan et al., 2013);
8. Personnel turnover rate (Erol et al., 2011);
9. Effectiveness of disciplinary management (Erol et al., 2011) and
10. Zero customer complaints or returns (Tseng, 2013).

2.2.3. Environmental dimension

The environmental dimension refers to the conditions surrounding human life. Environmental impact is affected significantly by the reclamation and development of enterprises, e.g., the use of hazardous substances, the discharge of waste water, the emission of harmful gases and the development of new factories. Enterprises must monitor and reduce effectively the damage to the environment. According to the literature, the following items regarding environmental aspects are obtained:

1. Reduction of the use of hazardous substances (Govindan et al., 2013; Joung et al., 2013; Shen et al., 2013; Tseng, 2013);
2. Reduction of energy use (Tseng, 2013);
3. Reduction of greenhouse gas emissions (Tseng, 2013);
4. Design of green products that can be disassembled, reused, or recycled without hazardous substances (Lee and Saen, 2012);
5. Noise emissions (Lee and Saen, 2012);
6. Effectiveness of reverse logistics systems (Erol et al., 2011);
7. Effectiveness of supplier monitoring (Erol et al., 2011);
8. Use of environmentally friendly raw materials: employing green recyclable materials for the packaging and manufacturing of goods (Tseng, 2013) and
9. Number of plants (Tseng, 2013).

This study integrates the above-mentioned factors on the three dimensions of sustainable development. Table 1 summarises the 31 sustainability indicators suggested by different authors and reveals

Table 1
Sustainability criteria.

Dimensions	Criteria	A	B	C	D	E	F	G
Economic dimension	Product cost	○			○			
	Ordering costs and logistics costs	○			○			
	On time delivery	○			○			
	Quality assurance	○			○			
	Rejection rate	○			○			
	Technology level	○			○			
	Research and design capability	○			○			
	Governance of the company				○			
	Corporate transparency and accountability				○			
	The number of shareholders	○						
	Profits	○						
	Investment	○						
Social dimension	Increase local community employment opportunities						○	
	Green image	○	○		○			
	Managers' commitment to green supply chain management	○	○		○			
	Employee environmental training	○	○		○			
	Employment practices							○
	Health and safety							○
	Local community feedback						○	
	Personnel turnover rate	○						
	The effectiveness of discipline management	○						
	Zero customer complaints or returns							○
Environmental dimension	Reduce the use of harmful raw materials			○		○	○	○
	Reduce energy use							○
	Reduce greenhouse gas emissions							○
	Green product design				○			
	Noise interference				○			
	Validity of reverse logistics system	○						
	Supplier monitoring effectiveness	○						
	Increase the use of green energy							○
	Use of green buildings							○

Key: A: Erol et al. (2011); B: Hong and Andersen (2011); C: Joung et al. (2013); D: Lee and Saen (2012); E: Shen et al. (2013); F: Govindan et al. (2013); G: Tseng (2013).

that numerous scholars have proposed different views of sustainable development. These 31 sustainability indicators are employed in this research for the analysis of the three major dimensions.

2.3. Fuzzy Delphi Method

In the abovementioned literature, many scholars in different fields have proposed a variety of sustainability indicators from several perspectives. However, many of these indicators may not be necessarily suitable for manufacturing SMEs. This study initially uses the fuzzy Delphi method to ask practical experts to screen these indicators, allowing the establishment of an importance index as the evaluation basis of the sustainable development performance for manufacturing SMEs.

The Delphi Method is an expert prediction method proposed by Dalkey and Helmer (1963). It is also known as the expert survey method, which is a means of communication that sends the questions to be resolved individually to various experts to ask for their opinions, collects and summarises the opinions of all experts and generates comprehensive comments. Afterwards, the comprehensive opinions and questions are fed back separately to the experts for another consultation. The experts may modify their original opinions according to the comprehensive opinions, and such subsequent views are gathered and summarised.

The Delphi method has been used widely in many management areas, including forecasting public policy, alternative solutions and project planning (Chang and Wang, 2006; Chang et al., 2011). However, the traditional Delphi method is considered to produce results of low convergence and entail loss of expert opinion. Given the shortcomings of the traditional Delphi approach, Ishikawa et al. (1993) combined it with fuzzy set theory and developed the Max-Min Fuzzy Delphi method and fuzzy integration algorithm to predict the spread of personal computers. Kuo et al. (2008) noted that compared with the traditional Delphi method, the fuzzy Delphi method has the advantage of requiring only a small number of samples to arrive at objective and reasonable results, which, in turn, can save time and costs for collecting expert opinions.

2.4. Grey relational analysis

After collecting data of performance indicators, quantifying the performance value is an issue that needs to be considered. Many multiple attributes of decision-making methods are available. Based on the obtained data characteristics, selecting a suitable evaluation method is necessary. The grey relational analysis (GRA) is a simple and extensively used effective assessment method. The entropy weight approach, which presents an objective weighting value and can eliminate the influence of human subjectivity, has been combined with the GRA method.

Proposed by Deng (1982), GRA is used to quantify the degree of relation between the measured factors. In addition to the advantages of simplicity and accuracy, GRA has the advantage of converting qualitative assessment factors for quantitative analysis and provides a comprehensive evaluation in multiple attribute decision making.

Extant literature provides numerous reports of GRA in recent years. Wang et al. (2013) applied a hybrid method of experimental design and GRA to investigate how to enhance market competitiveness by improving manufacturing capability. Aslan et al. (2012) used the GRA method to solve the optimisation problem of laboratory process parameters. In Maiyar et al. (2013), the optimum design parameters of the Ni-Cr-Ni alloy 718 super-alloy milling cutter were analysed by using Taguchi's GRA method. Wu (2002) utilised GRA to address a MADM problem. The benefits of GRA include easy comprehension and calculation, and provides a simple technique to help managers make decisions in a complicated environment. To choose the right suppliers to meet production needs, Tsai et al. (2003) conducted a survey to evaluate the performance of a new product for each supplier before launching mass production. Hou (2010) included intuitionistic fuzzy information to determine the weight of supplier selection criteria and employed the GRA method to sort the attributes. Kuo et al. (2008) combined GRA with data envelopment analysis to resolve routine decision-making problems in the workplace and identify the best option from multiple alternatives.

2.4.1. Entropy weight for the measurement criteria

The weight value of sustainability indicators is calculated through the entropy method. In physics, entropy represents natural phenomena in the one-way passage of time, denoting the property of irreversibility. Generally, entropy is used to determine the degree of equilibrium of various properties of a system energy distribution (Shannon, 1948). In a group, a composition of elements with evenly clustered distribution, being of equal probability, shows the highest entropy. Conversely, if the composition of elements shows uneven distribution of clustering, such as a particular group having high clustering probability, then the entropy will be reduced. Entropy is a proper noun for thermodynamics, and the concept of entropy is extended to many fields, such as of economy, society, and biology. To consider objective importance weight, this method has also been used to determine the relative importance of factors evaluated in decision-making models, for example, Peng et al. (2015) used the entropy method to determine the weights of indicators for measuring the sustainability of urban regeneration. Zhong and Yao (2017) developed an entropy weight model to objectively determine the criteria weights for supplier selection. Liu et al. (2018) also applied this method in the weighting process of evaluation indicator of carbon emissions reduction at the city level.

2.5. Rough set theory

After the performance is assessed, the performance values need to be classified into different groups. Then, the decision variables are imported in the rough set theory (RST) model. According to the theoretical steps, the relationship between the attribute variables and the decision variables is determined. Moreover, we use the sensitivity analysis method to identify the association rules between the sustainability indicators and the performance value to establish key sustainability indicators that produce high performance.

The advantage of RST is the rules that help users identify the relationships between sustainability indicators and performance. Rough set theory (RST) is a mathematical tool proposed by Pawlak (1982) that can deal with subjective and imprecise concepts and is a nonparametric data mining method. Considered superior to other methods of analysis that usually require the use of multivariate statistics and specific parameter assumptions, the RST method can incorporate tangible and intangible data into the assessment. RST has been applied very successfully in data processing. However, the classical rough set model of Pawlak (1982) can only deal directly with the nominal value. If the number of the keywords is continuous, then transformation into discrete data is necessary before calculation. However, such transformation may cause important information loss, which affect the result. By contrast, the neighbourhood rough set model, introduced by Hu et al. (2008), can handle numerical and even hybrid data.

The relevant rough set method literature in recent years are organised as follows. Bai and Sarkis (2011) proposed a method based on grey system and rough set theories for supplier performance management to assist organisations in evaluating supplier development programs. Lee et al. (2012) used RST and group hierarchical process analysis to evaluate a new service concept. Their study was divided into four phases. First, the four dimensions were identified. Second, domain experts compared the factors in the four dimensions. Third, individual judgment at the previous stage is combined into group judgment. Finally, the new service concept was prioritised according to the risk orientation of the decision maker. Bai and Sarkis (2013) utilised RST to explore the flexibility of reverse logistics and provide a method for decision-maker evaluation.

3. Research methods

A schematic illustration and steps of the proposed approaches for prioritizing the sustainability indicators is shown in Fig. 1.

3.1. Fuzzy Delphi Method

The application and steps of the fuzzy Delphi method are described as follows:

Step 1: Form an expert group. Identify experts according to the scope of knowledge required for the research project. The number of experts can be based on the size of the project to be forecasted and the breadth of the area involved. Generally, such number does not exceed 20.

Step 2: Ask all experts on the issues to be predicted and the related requirements, and include all background information on the issue. Then, written replies are provided by experts.

Step 3: Allow each expert to present his own evaluation based on the information he received. An interval value is given to indicate the degree of importance of the item under assessment. The 'minimum value' of this interval indicates the 'most conservative cognition value,' whereas the 'maximum value' denotes the 'optimal cognition value' of this expert's quantitative score for this evaluation item.

Step 4: Summarise the opinions of the experts for the first time, draw charts and compare them. Calculate the 'most conservative cognition value' and the 'optimal cognition value' given by all experts, and exclude the extreme value except for 'two times standard deviation.' Then, use fuzzy theory to calculate the minimum, geometric and maximum values of the remaining 'most conservative cognitive values,' and the 'most optimistic cognitive values' that were not excluded.

Step 5: According to the above steps, obtain the 'most conservative cognitive value' triangular fuzzy number for each assessment item as $M_2 = (l_2, m_2, u_2)$, and the triangular fuzzy number for 'the most optimistic cognitive value' as $M_1 = (l_1, m_1, u_1)$ (Fig. 2).

Step 6: Calculate the degree of consensus V. V is the 'consensus

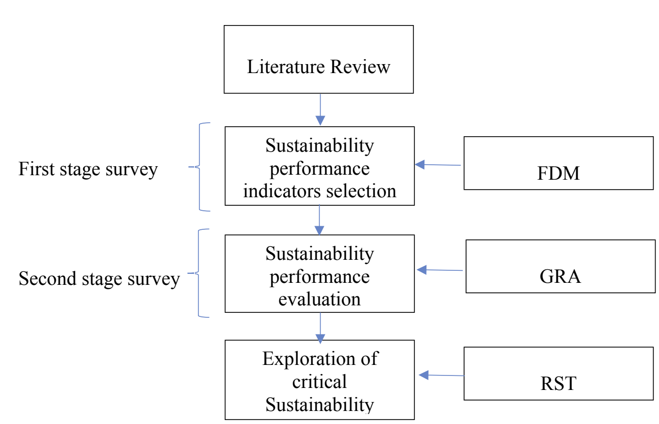

Fig. 1. Framework for the proposed approaches.

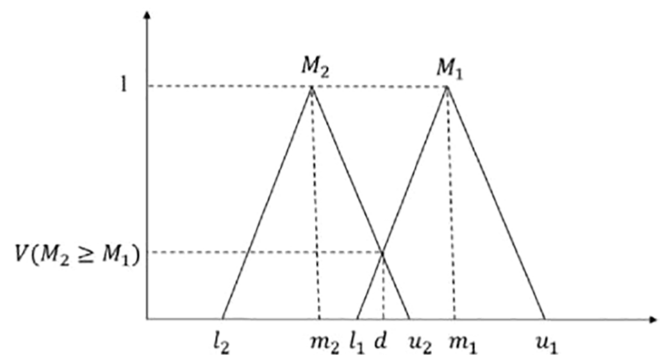

Fig. 2. Double triangular fuzzy number of maximum and minimum values.

importance value' of the experts' opinion. The higher the V expressed, the higher the consensus of the experts on the assessment item. The calculation of V involves three cases:

1.If the two triangular fuzzy numbers do not overlap, i.e. $(u_2 \leq l_1)$, then the opinions of experts have a consensus section. The 'consensus importance value' V of the evaluation item is represented as $V = (m_2 + m_1)/2$.
2.If the two triangular fuzzy numbers overlap, that is, $(u_2 > l_1)$ and $(Z^i < M^i)$, then the grey area of fuzzy relation $(Z^i = m_2 - l_1)$ is smaller than the interval of the experts' 'geometric mean of optimistic cognition' and 'geometric mean of conservative cognition', $M^i = m_1 - m_2$. The opinions of the experts that gave extreme values and the opinions of the other experts do not show great disparities, leading to opinion divergence.
3.If the two triangular fuzzy numbers overlap, i.e.$(u_2 > l_1)$, but the grey zone of the fuzzy relation (Z^i) is greater than the interval range of the two geometric mean values(M^i), then no consensus segments are present for the expert's opinion interval values, and the opinions of experts who gave views of extreme values differ from those of other experts, resulting in disagreement and divergence.

Step 7: Provide the experts with non-convergent assessment items and repeat Steps 3 to 7 to conduct another round of questionnaire surveys until all the assessment items can reach convergence and obtain the 'consensus importance value' V as follows:

$$V = \frac{[(u_2 \times m_1) - (l_1 \times m_2)]}{[(u_2 - m_2) + (m_1 - l_1)]}. \quad (1)$$

3.2. Grey relational analysis

GRA can be used to analyse an unclear and incomplete information system to conduct relational analysis and model construction. Moreover, through prediction and decision-making methods, GRA can be applied to explore and understand the situation of the system. Therefore, GRA can be employed to analyse the uncertainty of objects, multivariable inputs, discrete data and incomplete data effectively.

The steps of the calculation are detailed as follows:

Step 1: Identify the reference series A_0 and the comparison series A_i from the original data matrix D, where the reference series consist of a set of ideal objects of each influencing factor, $A_0 = (x_{01}, x_{02}, \ldots, x_{0j}, \ldots, x_{0n})$, where $j = 1, 2, 3, \ldots, n$. In addition, the series $A_i = (x_{i1}, x_{i2}, \ldots, x_{ij}, \ldots, x_{im})$ is represented by the performance values of the schemes, where $i = 1, 2, 3, \ldots, m$.

Step 2: Normalise the data of the original decision matrix D. Normalising data in GRA involves three methods: the larger-is-better (e.g., the benefit), nominal-is-best (e.g., the age) and smaller-is-better (e.g., the cost and defects) methods.

1. When the expectancy is larger-is-better, then it can be expressed by

$$x^*_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}. \quad (2)$$

2. When the expectancy is nominal-is-best, then it can be expressed by

$$x^*_{ij} = \frac{\left|x_{ij} - x_{0bj}\right|}{\max_i x_{ij} - x_{0bj}}. \quad (3)$$

3. When the expectancy is smaller-is-better, then it can be expressed by

$$x^*_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}. \quad (4)$$

Step 3: Calculate the grey relational distance:

$$\Delta_{0ij} = \left|x^*_{0j} - x^*_{ij}\right|, \quad (5)$$

where Δ_{0ij} is the measure of the distance between each normalised data and the normalised reference data.

Step 4: Calculate the grey relational coefficient, γ_{0ij} :

$$\gamma_{0ij} = \frac{\Delta min + \xi \Delta \max}{\Delta_{0ij} + \xi \Delta \max}, \quad (6)$$

where$\Delta\max = \max_i \max_j \Delta_{0ij}$,$\Delta\min = \min_i \min_j \Delta_{0ij}$ and $\xi \in [0,1] \cdot \xi$ is called the distinguished coefficient, which is used to control the size of the grey relational coefficient for the judgment. The general recommendation is set to 0.5. However, decision makers can choose different ξ values for the calculation according to their preferences.

Step 5: Calculate the grey relational grade, Γ_{0i}. For each alternative, the weighted average of the grey relational coefficient multiplied by the weight is the grey relational grade of the alternative. This value can be regarded as the score obtained for each alternative. If the score is high, then the alternative is more important:

$$\Gamma_{0i} = \sum_{j=1}^{n} \left[w_j \times \gamma_{0ij}\right], \quad (7)$$

where the weight value of w_j is calculated by entropy, as follows.

Suppose H represents the expected function, and I (X) is the amount of information for X and a random variable. If P represents the probability mass function of X, then the equation of entropy can be expressed as

$$H(X) = \sum_{i=1}^{n} P(X_i) I(X_i) = -\sum_{i=1}^{n} P(X_i) \log_b P(X_i), \quad (8)$$

where b is the base used, usually 2, 10 or the natural constant e.

Step 6: Rank the grey relational grade, and classify the decision variables according to the ranking order. Divide the variables into the following three categories:

1. High performance set: The ranking is between 1 and 7, such that $R^{+} = \{C_j : 1 \le R_j \le 7\}$.
2. Moderate performance set: The ranking is between 8 and 13, such that $R = \{C_j : 8 \le R_j \le 13\}$.
3. Low performance set: The ranking is between 14 and 20, such that $R^{-} = \{C_j : 14 \le R_j \le 20\}$.

The three performance sets of R^{+}, R ˆ_R^{-} are transformed into decision variables, 1, 2 and 3.

3.3. Rough set theory

The rough set model, a powerful computational intelligence tool proposed by Pawlak (1982), has proven to be effective in dealing with imprecise, uncertain and vague knowledge. In rough set theory, the upper approximation set determines the set that belong to the target group, whereas the lower approximation set represents the set that may belong to the target group. The difference between the upper and lower approximation sets constitutes the fuzzy set of the boundary region.

Basic definitions of rough set theory are given below (Bai and Sarkis, 2012, 2013; Jing, 2015):

Definition 1. Let U be the universe, a finite set of objects and R be a set of attributes. If X is a subset of U, then X ⊂ U, and the lower approximation set of X in R is defined as

$$\underline{R}X = \{X \in U \,|\, [X]_R \subseteq X\}. \quad (9)$$

Moreover, the upper approximation set of X in R is defined as

$$\overline{R}X = \{X \in U \,|\, [X]_R \cap X \ne \varphi\}. \quad (10)$$

The boundary of X in U is defined as

$$BN_R(X) = (\overline{R}X - \underline{R}X). \quad (11)$$

The blackened cells in Fig. 3 are represented as the objects being evaluated, and the white cells are outside the approximate sets. The black cells also constitute the lower approximation set, the grey cells are the upper approximation set and the edges of the grey cells are the boundaries.

A neighbourhood rough set is a new model that combines neighbour theory with rough set theory and can be used to process numerical or mixed values (Jing, 2015). The neighbourhood rough set extends the boundary dimension of the traditional rough set because it is established by the distance relationships of the attributes, allowing for the confirmation of objects that should be included in the rough set. Thus, the neighbourhood rough set can handle continuous numeric data directly. By contrast, the traditional rough set usually requires continuous data to be discretised or categorised for analysis. The classification of the data may cause the possibility of loss of information (Hu et al., 2008).

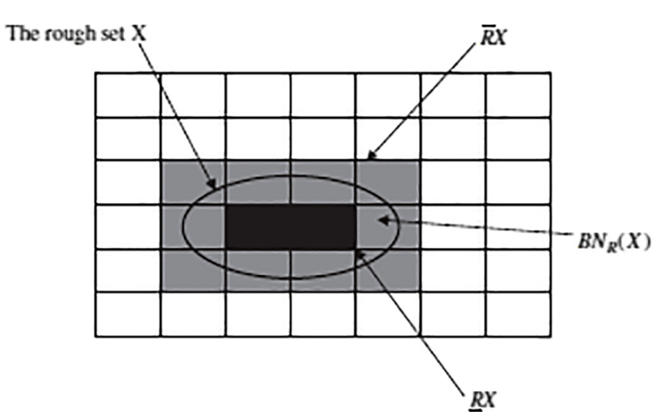

Fig. 3. Graph representation of a rough set theory (Bai and Sarkis, 2011).

Definition 2. Given an arbitrary object $X_i \in U$, B ⊆ C, C are conditional attributes. The neighbourhood relation $\delta_B(X_i)$ of X_i is defined in property space B as

$$\delta_B(X_i) = \left\{X_j \middle| X_j \in U, \Delta^B(X_i, X_j) \le \delta\right\}, \quad (12)$$

where Δ is a distance function. For $\forall X_1, X_2, X_3 \in U$, the following four conditions must be satisfied:

$$\begin{array}{l} 1.\ \Delta(X_1, X_2) \ge 0 \\ 2.\ \Delta(X_1, X_2) = 0 \text{ , If and only if } X_1, = X_2; \\ 3.\ \Delta(X_1, X_2) = \Delta(X_2, X_1); \text{and} \\ 4.\ \Delta(X_1, X_3) \le \Delta(X_1, X_2) + \Delta(X_2, X_3). \end{array} \quad (13)$$

Let V_{ij} represent the value of object i at attribute j. The Minkowsky distance function is defined as

$$\Delta_P(X_i, X_k) = \left(\sum_{i=1}^{N} \left|V_{ij} - V_{kj}\right|^P\right)^{1/P}. \quad (14)$$

When P = 1, it is defined as the Manhattan distance; when P = 2, it is defined as the Euclidean distance and when P = ∞, it is the Chebyshev distance. The Chebychev distance equation is

$$\Delta_\infty(X_i, X_k) = \max_j \left|V_{ij} - V_{kj}\right|. \quad (15)$$

Definition 3. Given a set of objects U, N, C and D with neighbourhood relations, we define a neighbourhood decision system (NDS) as follows: NDS = (U, C∪D, N). The system has two properties (condition and decision). The presence of the condition attribute in the whole domain indicates a neighbourhood relationship.

Definition 4. Given a neighbourhood decision system NDS $= U$, $C \cup D, N$, $X_1, X_2, \ldots, X_N$ is a subset of the object 1 to N. Suppose that $\delta_B(X_i)$ is the neighbourhood information generated by the attribute B∈C. Then attribute B is affected by decision D and the lower and upper approximation sets are defined as follows:

$$\underline{N_B} D = U_{i=1}^{N} \underline{N_B} X_i, \ \overline{N_B} D = U_{i=1}^{N} \overline{N_B} X_i, \quad (16)$$

when:

$$\underline{N_B} D = \{X_i | \delta_B(X_i) \subseteq X, X_i \in U\}, \overline{N_B} D = \{X_i | \delta_B(X_i) \cap X \ne \varphi, X_i \in U\}. \quad (17)$$

The decision boundary region of attribute B affected by decision D is defined as

$$B_N(D) = \left(\overline{N_B} D - \underline{N_B} D\right). \quad (18)$$

Definition 5. Given two sets A and B in the universe U, the definition of the accuracy of approximation of A in B is

$$I(A,B) = \frac{|A \cap B|}{|A|}, \text{where } A \neq \varphi \tag{19}$$

Definition 6. Given any subset X, X ⊆ U in the neighbourhood decision system (U, C∪D, N). When setting the threshold value K, 1 ≥ K ≥ 0.5, and the lower and upper approximation sets of X are as follows;

$$\underline{N^k}X = \{X_i | I(\delta(X_i), X) \geq k, X_i \in U\}, \overline{N^k}X = \{X_i | I(\delta(X_i), X) \geq 1 - k, X_i \in U\}. \tag{20}$$

Definition 7. Given a neighbourhood decision table (U, C∪D, N), the distance function Δ and the neighbourhood size δ, the ability of set B to approximate D is defined as follows:

$$\gamma_B(D) = \frac{|POS_B(D)|}{|U|}, \tag{21}$$

where |·| denotes cardinality. $\boldsymbol{POS_B(D)}$ is the lower approximation for the decision D and is defined as the union of the lower approximation of each decision class. $\gamma_{\boldsymbol{B}}(\boldsymbol{D})$ represents a dependency degree of D that depends on B.

4. Case analysis

In this study, the criteria for sustainability development includes the TBL. The literature review in Section 2 yielded the indicators in this research, including 12 economic criteria, 10 social criteria and 9 environmental criteria. We designed the first stage questionnaire and used fuzzy Delphi to screen the criteria of the three dimensions. Then, we developed the second stage questionnaire, which was issued to the manufacturing SMEs in central Taiwan. After the questionnaires were collected, GRA was used to evaluate the performance of the companies, and the resulting ranking values were divided into three types of decision variables. Finally, the core attributes were identified using RST, and the core attributes evaluated through sensitivity analysis.

4.1. First stage survey and the fuzzy Delphi method

Using the research steps in Section 3.2, we calculated the Zi value by performing the following steps:

1. Find the Zi value: The Zi value must be greater than 0; thus, a grey area must be present. If Zi is less than 0, we must examine whether the expert opinion is too extreme. If the number of samples is sufficient, the extreme item provided by the expert will be deleted. If not, the expert should be asked to re-visit the issue and explain his opinion.
2. Consensus value V: The higher the consensus value, the higher the expert consensus. When the consensus value is too low or falls below the threshold, the evaluation factor should be deleted.
3. Threshold Setting: The threshold is set according to the research needs, as determined by the researchers. In this study, threshold was set to 5.5. If V ≥ 5.5, then we accepted the criteria; however, if V < 5.5, then we delete the criteria (Table 2).

After screening of the fuzzy Delphi method, 16 important factors for sustainable development were identified (Table 3).

4.2. Second stage questionnaire and evaluation

The second stage questionnaire was constructed after obtaining the results of the fuzzy Delphi method. The research questions involved 16 criteria for sustainable development. The questionnaires were issued to a small and medium-sized enterprises in the manufacturing industry, specifically in an industrial area in the middle of Taiwan. Twenty copies of the questionnaire were issued, and all were returned.

4.2.1. Performance measurement with the GRA method

The GRA method was adopted after the collection of the questionnaires. This method calculates the grey relational value and uses sorting to classify the said value as the decision variable of RST. The original data (Table 4) were normalised through Step 2. The data of decision index x_n indicate the larger-is-better method, Equation (2) was adopted. Normalisation results are shown in Table 5. After normalisation of the data from Step 3, the grey relational distance was calculated to measure the gap between the normalised value and the normalised reference data. The grey relational distance is shown in Table 6. The grey relational coefficient was calculated by Step 4, using Equation (7) for the computation. The general recommendation value of ξ is 0.5; however, the decision maker can also choose another value of ξ to calculate according to their preference. The grey relational coefficient is shown in Table 7.

The grey relational grade was calculated from Step 5 by using Equation (8). Thus, we ascertained the score of each criterion, and the importance weights of attributes were calculated through the entropy approach, as shown in Section 2.8.2. The grey relational grade is shown in Table 8.

Finally, by sorting and classifying the grey relation degree, the results can be divided into the following categories:

1. High performance set: When their ranking is between 1 and 7, they are classified into the high-performance set, $R^+ = \{C_j : 1 \leq R_j \leq 7\}$.
2. Medium performance set: When their ranking is between 8 and 13, they are classified into the medium-performance set, $R = \{C_j : 8 \leq R_j \leq 13\}$.
3. Low performance set: When their ranking is between 14 and 20, they are classified into the low-performance set, $R^- = \{C_j : 14 \leq R_j \leq 20\}$.

The three types of R^+, R and R^- are transformed into decision variables, 1, 2 and 3. The results are shown in Table 9.

4.2.2. Use of rough set theory

GRA was used to determine the classification of decision variables. According to RST of Bai and Sarkis (2013), the six steps of application are as follows:

Step 1: Establish the original neighbourhood decision system. Based on information collected from the second phase of the questionnaire, 16 factors and 20 SMEs were established to form the original neighbourhood decision table, as shown in Section 4.2.1 and Table 4.

Step 2: Quantify the neighbourhood decision system. The original neighbour decision table was quantised. Taking the En1 indicator as an example, the best level was VH and the worst level was VL. The level of C2 was VH and the score was 1 after quantisation. Quantisation results are listed in Table 10.

Table 2
Criteria for sustainable development.

Dimensions	Factors for sustainable development	V
Environmental dimensions	1. Reduce the use of hazardous raw materials	5.82
	2. Reduce energy use	5.85
	3. Reduce greenhouse gas emissions	5.65
	4. Green product design	5.04
	5. Noise interference	5.83
	6. Effectiveness of the reverse logistics system	5.45
	7. Effectiveness of the supplier monitoring	5.23
	8. Increase the use of green energy	4.67
	9. Use of a green building	5.75
Social dimension	1. Increase employment opportunities for the local community	5.63
	2. Green image	4.63
	3. Manager's commitment to green supply chain management	4.56
	4. Environmental training for employees	6.31
	5. Employment practices	5.50
	6. Health and safety	5.64
	7. Local community feedback	5.40
	8. Personnel turnover rate	5.45
	9. Effectiveness of disciplinary management	5.67
	10. Zero customer complaints or returns	5.24
Economic dimension	1.Product costs	5.47
	2. Ordering cost and logistics cost	4.63
	3.On-time delivery	6.82
	4. Quality assurance	6.80
	5. Rejection rate	4.69
	6. Technology level	6.01
	7. R & D capacity and design capability	4.74
	8. Governance of the company	5.37
	9. Corporate transparency and accountability	5.41
	10. Number of shareholders	5.96
	11.Profit	6.16
	12.Investment	6.04

Table 3
Sustainability criteria after screening.

Dimensions	Sustainable development factors	Code
Environmental dimension	1. Reduce the use of hazardous materials	En1
	2. Reduce energy use	En2
	3. Reduce greenhouse gas emissions	En3
	4. Noise interference	En4
	5. Use of green building construction	En5
Social dimension	6. Increase local community employment opportunities	So1
	7. Employee environmental training	So2
	8. Employment practices	So3
	9. Health and safety	So4
	10. Effectiveness of disciplinary management	So5
Economic dimension	11. On-time delivery	Ec1
	12. Quality assurance	Ec2
	13. Technology level	Ec3
	14. Number of shareholders	Ec4
	15. Profits	Ec5
	16. Investment	Ec6

Step 3: Calculate the neighbourhood matrix. To evaluate the consistency, we refer to the normalisation of the equation for each factor operation as follows:

$$\widetilde{V_{ij}} = \frac{\left|V_{ij} - V_j^{min}\right|}{\left|V_j^{max} - V_j^{min}\right|}\ , \tag{22}$$

where V_{ij} is the quantisation value of the factor j of the company i, V_j^{min} is the minimum value of the factor j and V_j^{max} is the maximum value of the factor j. For example, with the En1 indicator, after entering Equation (22), $\frac{|0.8-0.8|}{|1-0.8|} = 0$, the results are shown in Table 11.

Next, the neighbourhood of each factor was calculated using the Chebyshev distance Equation (15). For example, the distance between C1 and C2 was $|0-1| = 1$ with respect to the criteria En1. The results are shown in Table 12.

Step 4: Find the upper and lower approximation sets and calculate the accuracy of the approximation. Based on the results of the normalisation of the previous step, we determined the neighbourhood for each performance measurement and established the relation matrix (upper approximation set). The adjacency matrix is defined as follows:

$$M_B(N) = (r_{ij})_{n\times n},\ \text{when}\ r_{ij} = \begin{cases} 1, & \Delta(x_i, x_j) \le \delta, \\ 0, & Otherwise. \end{cases} \tag{23}$$

For example, we set $\delta = 0.5$ and the value of this row is 13 as calculated from Table 13 with respect to $\delta_{En\ 1}(C1)$.

Table 4
Original performance data.

	En1	En2	En3	En4	En5	So1	So2	So3	So4	So5	Ec1	Ec2	Ec3	Ec4	Ec5	Ec6
C1	H	120	H	M	H	M	H	M	0	M	0.8	3	H	5	0.5	0.012
C2	VH	34.5	H	VL	L	M	M	VH	0	H	0.4	0	H	5	0.017	0.073
C3	VH	250	VH	M	VH	VH	VH	VH	1	VH	0.7	15	VH	10	0.2	0.012
C4	H	50	H	M	VH	VH	M	H	0	H	0.7	4	M	1	0.2	0.12
C5	VH	126	VH	L	M	VH	M	VH	0	M	0.85	0	M	3	0.2	0.2
C6	H	116	H	M	M	M	M	VH	0	H	0.65	1	H	4	0.4	0.016
C7	VH	65	H	H	L	H	M	VH	2	H	0.75	13	VH	4	0.13	0.26
C8	H	109	H	L	M	VH	L	H	0	VH	0.9	1	M	3	0.15	0.036
C9	VH	59	VH	VL	M	H	M	VH	0	H	0.5	0	M	4	0.2	0.089
C10	H	103	M	L	L	H	M	VH	1	VH	0.4	0	VH	4	0.15	0.061
C11	VH	90	H	VL	H	VH	L	H	0	H	0.45	0	M	5	0.12	0.051
C12	H	85	M	VL	L	VH	L	VH	0	H	0.5	0	M	4	0.03	0.024
C13	H	70	M	M	L	VH	L	VH	0	H	0.3	0	M	4	0.25	0.25
C14	H	150	M	L	L	VH	L	VH	2	VH	0.35	4	H	4	0.08	0.01
C15	VH	100	H	M	H	VH	M	VH	3	H	0.15	0	M	4	0.33	0.099
C16	H	121	L	L	M	H	L	H	0	H	0.5	0	H	4	0.18	0.043
C17	H	153	M	M	H	H	M	VH	2	VH	0.9	6	VH	1	0.02	0.002
C18	H	106	L	L	M	VH	L	H	0	H	0.6	0	M	2	0.16	0.06
C19	H	85	L	L	L	VH	VL	H	0	H	0.95	0	M	4	0.4	0.2
C20	H	205	M	H	L	H	L	H	3	H	0.65	4	H	5	0.16	0.013

Table 5
Normalisation.

	En1	En2	En3	En4	En5	So1	So2	So3	So4	So5	Ec1	Ec2	Ec3	Ec4	Ec5	Ec6
C1	0	0.397	0.667	0.667	0.667	0	0.75	0	0	0	0.813	0.2	0.5	0.444	1	0.039
C2	1	0	0.667	0	0	0	0.5	1	0	0.5	0.313	0	0.5	0.444	0	0.275
C3	1	1	1	0.667	1	1	1	1	0.333	1	0.688	1	1	1	0.379	0.039
C4	0	0.072	0.667	0.667	1	1	0.5	0.5	0	0.5	0.688	0.267	0	0	0.379	0.457
C5	1	0.425	1	0.333	0.333	1	0.5	1	0	0	0.875	0	0	0.222	0.379	0.767
C6	0	0.378	0.667	0.667	0.333	0	0.5	1	0	0.5	0.625	0.067	0.5	0.333	0.793	0.054
C7	1	0.142	0.667	1	0	0.5	0.5	1	0.667	0.5	0.75	0.867	1	0.333	0.234	1
C8	0	0.346	0.667	0.333	0.333	1	0.25	0.5	0	1	0.938	0.067	0	0.222	0.275	0.132
C9	1	0.114	1	0	0.333	0.5	0.5	1	0	0.5	0.438	0	0	0.333	0.379	0.337
C10	0	0.318	0.333	0.333	0	0.5	0.5	1	0.333	1	0.313	0	1	0.333	0.275	0.229
C11	1	0.258	0.667	0	0.667	1	0.25	0.5	0	0.5	0.375	0	0	0.444	0.213	0.19
C12	0	0.234	0.333	0	0	1	0.25	1	0	0.5	0.438	0	0	0.333	0.027	0.085
C13	0	0.165	0.333	0.667	0	1	0.25	1	0	0.5	0.188	0	0	0.333	0.482	0.961
C14	0	0.536	0.333	0.333	0	1	0.25	1	0.667	1	0.25	0.267	0.5	0.333	0.13	0.031
C15	1	0.304	0.667	0.667	0.667	1	0.5	1	1	0.5	0	0	0	0.333	0.648	0.376
C16	0	0.401	0	0.333	0.333	0.5	0.25	0.5	0	0.5	0.438	0	0.5	0.333	0.337	0.159
C17	0	0.550	0.333	0.667	0.667	0.5	0.5	1	0.667	1	0.938	0.4	1	0	0.006	0
C18	0	0.332	0	0.333	0.333	1	0.25	0.5	0	0.5	0.563	0	0	0.111	0.296	0.225
C19	0	0.234	0	0.333	0	1	0	0.5	0	0.5	1	0	0	0.333	0.793	0.767
C20	0	0.791	0.333	1	0	0.5	0.25	0.5	1	0.5	0.625	0.267	0.5	0.444	0.296	0.043

Table 6
Grey relational distance.

	En1	En2	En3	En4	En5	So1	So2	So3	So4	So5	Ec1	Ec2	Ec3	Ec4	Ec5	Ec6
C1	1	0.603	0.333	0.333	0.333	1	0.25	1	1	1	0.188	0.8	0.5	0.556	0	0.961
C2	0	1	0.333	1	1	1	0.5	0	1	0.5	0.688	1	0.5	0.556	1	0.725
C3	0	0	0	0.333	0	0	0	0	0.667	0	0.313	0	0	0	0.621	0.961
C4	1	0.928	0.333	0.333	0	0	0.5	0.5	1	0.5	0.313	0.733	1	1	0.621	0.543
C5	0	0.575	0	0.667	0.667	0	0.5	0	1	1	0.125	1	1	0.778	0.621	0.233
C6	1	0.622	0.333	0.333	0.667	1	0.5	0	1	0.5	0.375	0.933	0.5	0.667	0.207	0.946
C7	0	0.858	0.333	0	1	0.5	0.5	0	0.333	0.5	0.25	0.133	0	0.667	0.766	0
C8	1	0.654	0.333	0.667	0.667	0	0.75	0.5	1	0	0.062	0.933	1	0.778	0.725	0.868
C9	0	0.886	0	1	0.667	0.5	0.5	0	1	0.5	0.563	1	1	0.667	0.621	0.663
C10	1	0.682	0.667	0.667	1	0.5	0.5	0	0.667	0	0.688	1	0	0.667	0.725	0.771
C11	0	0.742	0.333	1	0.333	0	0.75	0.5	1	0.5	0.625	1	1	0.556	0.787	0.81
C12	1	0.766	0.667	1	1	0	0.75	0	1	0.5	0.563	1	1	0.667	0.973	0.915
C13	1	0.855	0.667	0.333	1	0	0.75	0	1	0.5	0.813	1	1	0.667	0.518	0.039
C14	1	0.464	0.667	0.667	1	0	0.75	0	0.333	0	0.75	0.733	0.5	0.667	0.87	0.969
C15	0	0.696	0.333	0.333	0.333	0	0.5	0	0	0.5	1	1	1	0.667	0.352	0.624
C16	1	0.599	1	0.667	0.667	0.5	0.75	0.5	1	0.5	0.563	1	0.5	0.667	0.663	0.841
C17	1	0.45	0.667	0.333	0.333	0.5	0.5	0	0.333	0	0.062	0.6	0	1	0.994	1
C18	1	0.668	1	0.667	0.667	0	0.75	0.5	1	0.5	0.438	1	1	0.889	0.704	0.775
C19	1	0.766	1	0.667	1	0	1	0.5	1	0.5	0	1	1	0.667	0.207	0.233
C20	1	0.209	0.667	0	1	0.5	0.75	0.5	0	0.5	0.375	0.733	0.5	0.556	0.704	0.957

Table 7
Grey relational coefficient.

	En1	En2	En3	En4	En5	So1	So2	So3	So4	So5	Ec1	Ec2	Ec3	Ec4	Ec5	Ec6
C1	0.333	0.453	0.6	0.6	0.6	0.333	0.667	0.333	0.333	0.333	0.727	0.385	0.5	0.474	1	0.342
C2	1	0.333	0.6	0.333	0.333	0.333	0.5	1	0.333	0.5	0.421	0.333	0.5	0.474	0.333	0.408
C3	1	1	1	0.6	1	1	1	1	0.429	1	0.615	1	1	1	0.446	0.342
C4	0.333	0.35	0.6	0.6	1	1	0.5	0.5	0.333	0.5	0.615	0.405	0.333	0.333	0.446	0.480
C5	1	0.465	1	0.429	0.429	1	0.5	1	0.333	0.333	0.8	0.333	0.333	0.391	0.446	0.683
C6	0.333	0.446	0.6	0.6	0.429	0.333	0.5	1	0.333	0.5	0.571	0.349	0.5	0.429	0.707	0.346
C7	1	0.368	0.6	1	0.333	0.5	0.5	1	0.6	0.5	0.667	0.789	1	0.429	0.395	1
C8	0.333	0.433	0.6	0.429	0.429	1	0.4	0.5	0.333	1	0.889	0.349	0.333	0.391	0.408	0.365
C9	1	0.361	1	0.333	0.429	0.5	0.5	1	0.333	0.5	0.471	0.333	0.333	0.429	0.446	0.430
C10	0.333	0.423	0.429	0.429	0.333	0.5	0.5	1	0.429	1	0.421	0.333	1	0.429	0.408	0.393
C11	1	0.402	0.6	0.333	0.6	1	0.4	0.5	0.333	0.5	0.444	0.333	0.333	0.474	0.389	0.382
C12	0.333	0.395	0.429	0.333	0.333	1	0.4	1	0.333	0.5	0.471	0.333	0.333	0.429	0.339	0.353
C13	0.333	0.374	0.429	0.6	0.333	1	0.4	1	0.333	0.5	0.381	0.333	0.333	0.429	0.491	0.928
C14	0.333	0.519	0.429	0.429	0.333	1	0.4	1	0.6	1	0.4	0.405	0.5	0.429	0.365	0.34
C15	1	0.418	0.6	0.6	0.6	1	0.5	1	1	0.5	0.333	0.333	0.333	0.429	0.587	0.445
C16	0.333	0.455	0.333	0.429	0.429	0.5	0.4	0.5	0.333	0.5	0.471	0.333	0.5	0.429	0.43	0.373
C17	0.333	0.526	0.429	0.6	0.6	0.5	0.5	1	0.6	1	0.889	0.455	1	0.333	0.335	0.333
C18	0.333	0.428	0.333	0.429	0.429	1	0.4	0.5	0.333	0.5	0.533	0.333	0.333	0.36	0.415	0.392
C19	0.333	0.395	0.333	0.429	0.333	1	0.333	0.5	0.333	0.5	1	0.333	0.333	0.429	0.707	0.683
C20	0.333	0.705	0.429	1	0.333	0.5	0.4	0.5	1	0.5	0.571	0.405	0.5	0.474	0.415	0.343

Table 8
Grey relational degree.

weighting	0.092	0.078	0.088	0.081	0.085	0.091	0.085	0.092	0.066	0.092	0.082	0.067	0.090	0.078	0.062	0.036	
	En1	En2	En3	En4	En5	So1	So2	So3	So4	So5	Ec1	Ec2	Ec3	Ec4	Ec5	Ec6	總分
C1	0.031	0.035	0.053	0.049	0.051	0.030	0.057	0.031	0.022	0.031	0.060	0.026	0.045	0.037	0.062	0.012	0.631
C2	0.092	0.026	0.053	0.027	0.028	0.030	0.043	0.092	0.022	0.046	0.035	0.022	0.045	0.037	0.021	0.015	0.634
C3	0.092	0.078	0.088	0.049	0.085	0.091	0.085	0.092	0.028	0.092	0.051	0.067	0.090	0.078	0.028	0.012	1.106
C4	0.031	0.027	0.053	0.049	0.085	0.091	0.043	0.046	0.022	0.046	0.051	0.027	0.030	0.026	0.028	0.017	0.671
C5	0.092	0.036	0.088	0.035	0.036	0.091	0.043	0.092	0.022	0.031	0.066	0.022	0.030	0.031	0.028	0.024	0.767
C6	0.031	0.035	0.053	0.049	0.036	0.030	0.043	0.092	0.022	0.046	0.047	0.023	0.045	0.034	0.044	0.012	0.642
C7	0.092	0.029	0.053	0.081	0.028	0.046	0.043	0.092	0.040	0.046	0.055	0.053	0.090	0.034	0.025	0.036	0.841
C8	0.031	0.034	0.053	0.035	0.036	0.091	0.034	0.046	0.022	0.092	0.073	0.023	0.030	0.031	0.025	0.013	0.669
C9	0.092	0.028	0.088	0.027	0.036	0.046	0.043	0.092	0.022	0.046	0.039	0.022	0.030	0.034	0.028	0.015	0.688
C10	0.031	0.033	0.038	0.035	0.028	0.046	0.043	0.092	0.028	0.092	0.035	0.022	0.090	0.034	0.025	0.014	0.685
C11	0.092	0.031	0.053	0.027	0.051	0.091	0.034	0.046	0.022	0.046	0.037	0.022	0.030	0.037	0.024	0.014	0.657
C12	0.031	0.031	0.038	0.027	0.028	0.091	0.034	0.092	0.022	0.046	0.039	0.022	0.030	0.034	0.021	0.013	0.598
C13	0.031	0.029	0.038	0.049	0.028	0.091	0.034	0.092	0.022	0.046	0.031	0.022	0.030	0.034	0.031	0.033	0.641
C14	0.031	0.040	0.038	0.035	0.028	0.091	0.034	0.092	0.040	0.092	0.033	0.027	0.045	0.034	0.023	0.012	0.694
C15	0.092	0.033	0.053	0.049	0.051	0.091	0.043	0.092	0.066	0.046	0.027	0.022	0.030	0.034	0.037	0.016	0.781
C16	0.031	0.036	0.029	0.035	0.036	0.046	0.034	0.046	0.022	0.046	0.039	0.022	0.045	0.034	0.027	0.013	0.540
C17	0.031	0.041	0.038	0.049	0.051	0.046	0.043	0.092	0.040	0.092	0.073	0.030	0.090	0.026	0.021	0.012	0.773
C18	0.031	0.033	0.029	0.035	0.036	0.091	0.034	0.046	0.022	0.046	0.044	0.022	0.030	0.028	0.026	0.014	0.568
C19	0.031	0.031	0.029	0.035	0.028	0.091	0.028	0.046	0.022	0.046	0.082	0.022	0.030	0.034	0.044	0.024	0.624
C20	0.031	0.055	0.038	0.081	0.028	0.046	0.034	0.046	0.066	0.046	0.047	0.027	0.045	0.037	0.026	0.012	0.665

Table 9
Classification of grey relational grade.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
Ranking	13	17	1	9	5	15	2	11	8	10	16	18	12	7	3	20	4	19	14	6
Decision variable	3	3	1	2	1	2	1	2	1	2	2	3	3	1	1	3	1	3	3	2

Then, we calculated the lower approximation set according to Table 13. Subsequently, we defined Equation (17) to calculate the matrix:

$$M_B^D(N) = (r_{ij})_{n\times n}, \text{when } r_{ij} = \begin{cases} 1, & \Delta(x_i, x_j) \le \delta, D_i = D_j \\ 0, & otherwiae, \end{cases} \quad (24)$$

For example, from Table 14, the value of $\delta_{En\ 1}^{D=2}(\mathrm{C1})$ is summed to 8. Finally, we used Equation (19) to calculate the decision rate, $\mathrm{I}(\delta(\mathrm{C1}), \mathrm{X}) = 8/13 = 0.65$.

Step 5: Calculate the degree of dependence. We set $k = 0.6$ to determine the individual $\mathrm{C\,I}(\delta(x_i), \mathrm{X}) \ge \mathrm{K}$. For example, if the judgment rate of CI is 0.615, $\mathrm{I}(\delta(\mathrm{C}_1), \mathrm{X}) \ge 0.6$, so $\mathrm{POS}_{\mathrm{En1}}(D) = 13$. Then, we can calculate the dependency of each attribute according to Equation (21). Taking En1 as an example, $\gamma_{Atr\cup En1}(D) = \frac{|POS_{Atr\cup En1}(D)|}{|U|} = 13/20 = 0.65$.

Step 6: Select the reduction set attribute. Let $\varepsilon = 0.25$, with En4 as example, $\mathrm{Sig}_1(\mathrm{En1}, \mathrm{En1}, \mathrm{D}) = 0.65 > 0.25$, and thus, $\mathrm{Atr} = \mathrm{Atr}\cup\mathrm{En1} = \{En1\}$. Finally, this set property is {En4, So4, En1, Ec3} or {4, 9, 1, 13} with $\delta = 0.5$ and $k = 0.6$. We repeated Steps 3 to 6. The results of the sensitivity analysis are shown in Table 15, with the selected ranges of $0 \le \delta \le 0.5$ and $0.5 \le k \le 1$.

Table 10
Quantification of the neighbourhood decision table.

	En1	En2	En3	En4	En5	So1	So2	So3	So4	So5	Ec1	Ec2	Ec3	Ec4	Ec5	Ec6	DV
C1	0.8	120	0.8	0.6	0.8	0.6	0.8	0.6	0	0.6	0.8	3	0.8	5	0.5	0.012	3
C2	1	34.5	0.8	0.2	0.4	0.6	0.6	1	0	0.8	0.4	0	0.8	5	0.017	0.073	3
C3	1	250	1	0.6	1	1	1	1	1	1	0.7	15	1	10	0.2	0.012	1
C4	0.8	50	0.8	0.6	1	1	0.6	0.8	0	0.8	0.7	4	0.6	1	0.2	0.12	2
C5	1	126	1	0.4	0.6	1	0.6	1	0	0.6	0.85	0	0.6	3	0.2	0.2	1
C6	0.8	116	0.8	0.6	0.6	0.6	0.6	1	0	0.8	0.65	1	0.8	4	0.4	0.016	2
C7	1	65	0.8	0.8	0.4	0.8	0.6	1	2	0.8	0.75	13	1	4	0.13	0.26	1
C8	0.8	109	0.8	0.4	0.6	1	0.4	0.8	0	1	0.9	1	0.6	3	0.15	0.036	2
C9	1	59	1	0.2	0.6	0.8	0.6	1	0	0.8	0.5	0	0.6	4	0.2	0.089	1
C10	0.8	103	0.6	0.4	0.4	0.8	0.6	1	1	1	0.4	0	1	4	0.15	0.061	2
C11	1	90	0.8	0.2	0.8	1	0.4	0.8	0	0.8	0.45	0	0.6	5	0.12	0.051	2
C12	0.8	85	0.6	0.2	0.4	1	0.4	1	0	0.8	0.5	0	0.6	4	0.03	0.024	3
C13	0.8	70	0.6	0.6	0.4	1	0.4	1	0	0.8	0.3	0	0.6	4	0.25	0.25	3
C14	0.8	150	0.6	0.4	0.4	1	0.4	1	2	1	0.35	4	0.8	4	0.08	0.01	1
C15	1	100	0.8	0.6	0.8	1	0.6	1	3	0.8	0.15	0	0.6	4	0.33	0.099	1
C16	0.8	121	0.4	0.4	0.6	0.8	0.4	0.8	0	0.8	0.5	0	0.8	4	0.18	0.043	3
C17	0.8	153	0.6	0.6	0.8	0.8	0.6	1	2	1	0.9	6	1	1	0.02	0.002	1
C18	0.8	106	0.4	0.4	0.6	1	0.4	0.8	0	0.8	0.6	0	0.6	2	0.16	0.06	3
C19	0.8	85	0.4	0.4	0.4	1	0.2	0.8	0	0.8	0.95	0	0.6	4	0.4	0.2	3
C20	0.8	205	0.6	0.8	0.4	0.8	0.4	0.8	3	0.8	0.65	4	0.8	5	0.16	0.013	2
V_j^{max}	1	250	1	0.8	1	1	1	1	3	1	0.95	15	1	10	0.5	0.26	
V_j^{min}	0.8	34.5	0.4	0.2	0.4	0.6	0.2	0.6	0	0.6	0.15	0	0.6	1	0.017	0.002	

Table 11
Normalised matrix.

	En1	En2	En3	En4	En5	So1	So2	So3	So4	So5	Ec1	Ec2	Ec3	Ec4	Ec5	Ec6	DV
C1	0	0.397	0.667	0.667	0.667	0	0.75	0	0	0	0.813	0.2	0.5	0.444	1	0.039	3
C2	1	0	0.667	0	0	0	0.5	1	0	0.5	0.313	0	0.5	0.444	0	0.275	3
C3	1	1	1	0.667	1	1	1	1	0.333	1	0.688	1	1	1	0.379	0.039	1
C4	0	0.072	0.667	0.667	1	1	0.5	0.5	0	0.5	0.688	0.267	0	0	0.379	0.457	2
C5	1	0.425	1	0.333	0.333	1	0.5	1	0	0	0.875	0	0	0.222	0.379	0.767	1
C6	0	0.378	0.667	0.667	0.333	0	0.5	1	0	0.5	0.625	0.067	0.5	0.333	0.793	0.054	2
C7	1	0.142	0.667	1	0	0.5	0.5	1	0.667	0.5	0.75	0.867	1	0.333	0.234	1	1
C8	0	0.346	0.667	0.333	0.333	1	0.25	0.5	0	1	0.938	0.067	0	0.222	0.275	0.132	2
C9	1	0.114	1	0	0.333	0.5	0.5	1	0	0.5	0.438	0	0	0.333	0.379	0.337	1
C10	0	0.318	0.333	0.333	0	0.5	0.5	1	0.333	1	0.313	0	1	0.333	0.275	0.229	2
C11	1	0.258	0.667	0	0.667	1	0.25	0.5	0	0.5	0.375	0	0	0.444	0.213	0.190	2
C12	0	0.234	0.333	0	0	1	0.25	1	0	0.5	0.438	0	0	0.333	0.027	0.085	3
C13	0	0.165	0.333	0.667	0	1	0.25	1	0	0.5	0.188	0	0	0.333	0.482	0.961	3
C14	0	0.536	0.333	0.333	0	1	0.25	1	0.667	1	0.25	0.267	0.5	0.333	0.130	0.031	1
C15	1	0.304	0.667	0.667	0.667	1	0.5	1	1	0.5	0	0	0	0.333	0.648	0.376	1
C16	0	0.401	0	0.333	0.333	0.5	0.25	0.5	0	0.5	0.438	0	0.5	0.333	0.337	0.159	3
C17	0	0.550	0.333	0.667	0.667	0.5	0.5	1	0.667	1	0.938	0.4	1	0	0.006	0	1
C18	0	0.332	0	0.333	0.333	1	0.25	0.5	0	0.5	0.563	0	0	0.111	0.296	0.225	3
C19	0	0.234	0	0.333	0	1	0	0.5	0	0.5	1	0	0	0.333	0.793	0.767	3
C20	0	0.791	0.333	1	0	0.5	0.25	0.5	1	0.5	0.625	0.267	0.5	0.444	0.296	0.043	2

According to Table 15, the main core attributes were determined by the frequency of occurrences. Non-core attributes are attributes not present in the overall sensitivity analysis. Results show that ‘3’ (i.e., En3, reduction of greenhouse gas emissions) is the most critical sustainability indicator, followed by ‘11’ (Ec1, on-time delivery), ‘12’ (Ec2, quality assurance) and ‘15’ (Ec5, profit). By contrast, ‘10’ (So5, the effectiveness of disciplinary management) is a non-core attribute.

4.3. Results and discussion

From the managerial implementation perspective, the most important factor in improving sustainability performance for manufacturing SMEs in Taiwan is in the environmental dimension, that is, reduction of greenhouse gas emissions. Given that greenhouse gas emissions are considered to be the main environmental burden, Bocken et al. (2011) advised goods manufacturers to reduce gradually their greenhouse gas emissions from product consumption to processes. Manufacturing MSEs in Taiwan should also reduce greenhouse gas emission from the product life cycle perspective, that is, from product design, material selection, alternative delivery options, consumer behavior observation, to the choice of supply chains. Moreover, the factors that promote sustainability are related to economic dimensions. Manufacturers must pursue multiple competitive advantages, including cost reduction, quality improvement of products and services, and on-time delivery guarantee to maintain the competitive edge and gain profit (Hayes et al., 1988; Ward and Duray, 2000; Soosay et al., 2016). With the aim of lowering costs, inventory reduction, reliability and on-time delivery are critical to the buyer. Most manufacturing SMEs in Taiwan are suppliers to large companies. Given the increasing complexity of a manufacturing environment and the many uncertainties and risk factors, on-time delivery and quality assurance have always been difficult for manufacturers. Many strategies to improve competitive advantage are proposed and implemented constantly, such as total quality management,

Table 12
Chebychev distances.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	DV
C1	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	3
C2	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	3
C3	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	1
C4	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	2
C5	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	1
C6	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	2
C7	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	1
C8	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	2
C9	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	1
C10	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	2
C11	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	2
C12	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	3
C13	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	3
C14	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1
C15	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	1
C16	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	3
C17	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1
C18	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	3
C19	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	3
C20	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	2

Table 13
Relationship matrix between enterprises with respect to En1 ($M_{En1}(20)$).

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	DV	Sum
C1	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	3	13
C2	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	3	7
C3	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1	7
C4	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	2	13
C5	0	1	1	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	13
C6	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	2	13
C7	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1	7
C8	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	2	13
C9	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1	7
C10	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	2	13
C11	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	2	7
C12	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	3	13
C13	1	0	0	1	1	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	3	14
C14	1	0	0	1	1	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	1	14
C15	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1	7
C16	1	0	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	3	13
C17	1	0	0	1	1	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	1	14
C18	1	0	0	1	1	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	3	14
C19	1	0	0	1	1	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	3	14
C20	1	0	0	1	1	1	0	1	0	1	0	1	1	1	0	1	1	1	1	1	2	14

Table 14
The relationship matrix across enterprises with respect to En1 ($\delta_{En\ 1}^{D=2}(20)$).

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	Sum	Judgment rate
C1	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1	8	0.615
C2	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0.286
C3	0	0	1	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	5	0.714
C4	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	5	0.385
C5	0	0	1	0	1	0	1	0	1	0	0	0	0	1	1	0	1	0	0	0	7	0.538
C6	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1	8	0.615
C7	0	0	1	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	5	0.714
C8	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	5	0.385
C9	0	0	1	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	5	0.714
C10	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	5	0.385
C11	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0.286
C12	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1	8	0.615
C13	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1	8	0.571
C14	0	0	0	1	1	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	6	0.429
C15	0	0	1	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	5	0.714
C16	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1	8	0.615
C17	0	0	0	1	1	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	6	0.429
C18	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1	8	0.571
C19	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1	8	0.571
C20	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1	8	0.571

Table 15
Neighbourhood approximate set sensitivity analysis.

δ	k	Atr	δ	k	Atr	δ	k	Atr
0	0.5	2,16,11,15,12,8,9,14,3,5,7,4,1,6,13	0.2	0.5	8,9,12,3,5,7,4,1,6,13	0.4	0.5	8,9,1,6,13
0	0.6	2,16,15,12,11,3	0.2	0.6	3	0.4	0.6	
0	0.7	2,16,15,11,12,3	0.2	0.7	3	0.4	0.7	
0	0.8	2,16,15,11,12	0.2	0.8		0.4	0.8	
0	0.9	2,16,15,11,12	0.2	0.9		0.4	0.9	
0	1	2,16,15,11,12	0.2	1		0.4	1	
0.1	0.5	8,9,16,12,15,11,14,2,3,5,7,4,1,6,13	0.3	0.5	8,9,3,5,4,1,6,13	0.5	0.5	9,1
0.1	0.6	3,11,15	0.3	0.6	3	0.5	0.6	
0.1	0.7	3	0.3	0.7	3	0.5	0.7	
0.1	0.8		0.3	0.8		0.5	0.8	
0.1	0.9		0.3	0.9		0.5	0.9	
0.1	1		0.3	1		0.5	1	

just-in-time production, and 6σ strategies. We consider these factors to be competitive advantages for Taiwanese manufacturing MSEs to win orders. We also believe Taiwan SMEs should actively initiate effective strategic solutions to enhance their competitive advantage. The results of this study may provide industry reference for enhancing the competitiveness of enterprises and serve as reference for promoting sustainable development.

5. Conclusion and recommendations

In this paper, a comprehensive review of the sustainability criteria and an integrated model to identify the critical sustainability indicators in SMEs in Taiwan are provided. The conclusions and contributions of this study are described below. The limitations and future research directions are also illustrated.

5.1. Conclusion and contribution

Sustainable manufacturing is related to the conversion of input materials and energy into manufactured goods. Generally, sustainable manufacturing is a key component of sustainable development that would balance the three main requirements. Specifically, manufacturing SMEs is a main object of concern. These enterprises must strengthen their sustainability practices and enhance their management strategies to respond to changing environments and maintain a sustainable earth.

Unlike large companies, SMEs have considerable difficulty in achieving sustainable enterprises. SMEs should utilize their limited resources effectively and consider the differences in elaborating their sustainable development strategies. This study uses a decision-making model with integrated, quantitative multiple attributes to analyse key factors of sustainable development in the implementation of sustainable production in manufacturing SMEs. The results show which sustainability indicators are in the most critical position. This study selected manufacturing SMEs in Taiwan as the object of analysis. Findings show the environmental indicator of 'reduction of greenhouse gas emissions', and the economic indicators of 'on-time delivery,' 'quality assurance' and 'profit' are the core indicators more related to the high performance of SMEs in Taiwan.

The sustainability measure used in this study is based on an extensive literature review and has not included missing indicators in the literature. The results obtained in our existing knowledge body have not expanded into new areas. However, we focus our attention on SMEs to help them find key indicators. The contribution of this research in expanding the quantitative research on the sustainable development of SMEs. The results show that to improve the performance of sustainability development, Taiwan's SMEs must pay attention to the issue of environmental pollution. This phenomenon is similar to that of many developing countries. Environment protection efforts are often ignored when the focus of development tends to economic development. The secondary indicators show Taiwanese SMEs are still struggling to compete on the issue of market competition, reducing costs, on-time delivery and improving quality. The focus of these economic issues is to improve the efficiency and effectiveness of SMEs, that is, they need to join a professional management system.

5.2. Research limitations and future research

Review of extant literature shows sustainable development has a very wide range of scope. The SMEs in manufacturing industry can only use self-interpretation approach toward their goal of sustainable development and their goals and emphasis could be based on their own different perspectives. This study also evaluated SMEs in the manufacturing industry in central Taiwan as an empirical object, and thus, its limitations and scope are as follows:

1. Sustainable development is a relatively new concept to SMEs and thus, enterprises have gradually started to introduce into their strategic plans. Discussions with various experts revealed that clear quantitative data on sustainability indicators cannot be provided by the companies. Instead, qualitative data were used as basis for the evaluation.
2. The sources of data collected for this study are limited to an industrial area in central Taiwan. Given the difficulties in obtaining relevant information, only 20 manufacturing SMEs were analysed.
3. The 20 manufacturing SMEs in this study had sizes of approximately 10–80 employees making the results not suitable for inference to large enterprises.

Based on the method of multi attribute decision making and data mining, the results of this combined evaluation model of sustainable development can provide important information for manufacturing SMEs. The recommendations and future research directions are as follows:

Given the small number of samples, follow-up research can increase the sample size and expand the database to obtain more objective and accurate results. Moreover, in this study, the classification of decision variables for rough set analysis involved a sorting classification method. Future studies can use other data mining methods, such as cluster analysis, decision tree or multi-objective programming, to classify the decision variables with additional samples, such that a more accurate and objective classification method can be obtained. Furthermore, fuzzy Delphi method was used for factor screening in this research. Upcoming investigations can use such method with support vector machines, random forests or K-mean methods to verify and compare the results. Moreover, for the method of multi-attribute decision-making, various methods can be used for performance evaluation. Prospective investigations can utilize different evaluation models with the RST model and compare the results for consistency.

With the regard to the manner of moving away from current unsustainable patterns in production and consumption of material goods, researchers should continue to experiment on how manufacturing strategies can be used to create managerial momentum, not only in the direction of greater competitiveness but also greater sustainability.

5.3. Comparisons with previous research and implications of practical application

Compared with previous related studies, this study follows the extension of Hsu et al. (2017) arguments that the formation of mathematical models with obtainable data in the sustainability development is an area with relatively scarce research, but nevertheless is an important field to explore. In this research, we propose a different quantitative approach that is a new combination method in the literature. More specifically, we focus on an area of research that has gained less attention from manufacturing SMEs. In addition, with regard to the application of the criteria contained in the three dimensions, researchers have proposed a significant number of sustainable development indicators from different research fields. In the literature, the scholars proposed the general connotation, but when applied to a particular research field and due to the difference in geographical locations or different systems, the sustainability development of concern in practice is likely to produce considerable variation. Therefore, the use of indicators applied in this study is also different from related research. From an applicative point of view, considering all presented indicators in the research of SMEs is impossible. We can only select important indicators relevant to the evaluation model. Moreover, the use of indicators can also produce differences because the research object is Taiwan's SMEs, and because of the need to obtain quantifiable data of relevant indicators.

The benefits of the proposed method from other similar methods is as follows. In the research literature on related quantitative methods, some studies use relatively simple models for evaluation, in which the considerations could be insufficient. This study uses FDM to screen important criteria, evaluates performance with GRA and finally uses RST to summarise the rules of decision making. These steps have the advantage of extensive consideration. Moreover, from a practical applications perspective, the proposed method is easy to use, and does not require any of special program or software package. Using Microsoft Excel can yield the final results. The results of this research will assist managers in clarifying the critical sustainability development indicators and providing a clear picture of how to make appropriate decisions.

The limitation of using this method is that, as mentioned above, SMEs are less concerned with sustainable development and are therefore less aware of the implications of sustainable development. In addition, the survey on environmental factors is a relatively sensitive issue for SMEs, causing them to have lower willingness to cooperate with the survey. More efforts are required to communicate with the individuals who filled out the questionnaire in the investigation.

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