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Abstract

Purpose – The purpose of this paper is to enhance the understanding of sustainable supply chain management (SSCM) and provide a comprehensive and quantitative method to assess performance.
Design/methodology/approach – The study applied interval-valued triangular fuzzy numbers associated with grey relational analysis to improve the insufficient information and overcome the incomplete system under uncertainty.
Findings – The findings support the argument that the triple bottom line is insufficient to cover the entire concept of SSCM; in particular, the aspects of operations, stakeholders and resilience have not been addressed in previous studies.
Research limitations/implications – The results reveal that the triple bottom line concept is insufficient to illustrate the principles of SSCM and to provide an extensive basis for theory development. The aspects and criteria considered in the study only relate to the studied company and may need to be reviewed when applied to other industries.
Practical implications – The methodology and findings of the study demonstrate the core applications of criteria ranking and identify priority areas that utilize less investment but that may maintain the studied company's current performance. Suggestions for the prioritization of criteria to enhance SSCM performance are provided.
Originality/value – The present study provides three valuable contributions. First, it adopts collaboration theory to furnish a theoretical foundation for SSCM. Second, the proposed hybrid method is able to overcome uncertainty and subsequently evaluate SSCM while utilizing incomplete and imprecise information. Third, the evaluation provides significant results for consideration in decision making by the studied company.

Keywords Sustainable supply chain management, Collaboration theory, Grey relational analysis, Interval-valued triangular fuzzy numbers

Paper type Research paper

1. Introduction

Establishing a sustainable business has become a critical challenge for companies, particularly those in the high-tech and electronics industry, due to stringent environmental regulations and policies implemented in the recent years. The European Union has implemented several regulations that directly impact companies' operations, such as WEEE, REACH and RoHS (Wu *et al.*, 2015). These actions have been discussed and highlighted in the literature on environmental issues and operations, but these

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studies did not extend the discussion to economic and social issues (Ahi and Searcy, 2013; Zhu *et al.*, 2013). Thus, Carter and Rogers (2008) introduced the triple bottom line concept (with environmental, economic and social aspects) to sustainable supply chain management (SSCM). It allows companies to generate positive effects on the environment and society while simultaneously maintaining long-term economic benefits and competitive advantage.

Seuring and Müller (2008) emphasized the need for SSCM to address the environmental and social issues that are increasingly penetrating the public's consciousness, and the authors discussed both triggers and opportunities in supply chain management (SCM) practices. SSCM requires collaboration that involves both environmental complexity and stakeholder control over the environment, together with a relationship between individual participants' self-interest and the collective interests of everyone involved in the collaborative alliance (Lozano, 2008). Although several studies have attempted to propose a concept and framework for the development of SSCM, its clear meaning and theoretical basis are still insufficient (Ahi and Searcy, 2013; Seuring, 2013; Morali and Searcy, 2013; Brandenburg *et al.*, 2014), particularly regarding the combination of incomplete information and the interrelationships that exist in the decision-making process at the firm and industry levels (Su *et al.*, 2015).

Therefore, although there have been attempts to provide a theoretical basis and a quantitative method for evaluating SSCM performance, the application of specific assessments remains limited (Gold *et al.*, 2010; Beske, 2012). Hence, this study adopts the collaboration theory to enhance the understanding of SSCM by integrating sustainability and SCM. It then integrates interval-valued triangular fuzzy numbers (IVTFNs) and grey relational analysis (GRA) to overcome the imprecise information and compensate for systemic insufficiency during the evaluation process. Although previous studies have attempted to use statistical methods to explore the diverse aspects and address the theory, an efficient assessment to evaluate SSCM performance is still lacking.

Thus, the objective of this study is to provide not only a theoretical basis but also a quantitative tool for firms to evaluate SSCM performance. Aspects and criteria are also proposed to strengthen the understanding and development of SSCM. The results of this study can assist aggressive companies that are implementing SSCM to improve their sustainable performance. The remainder of this paper is structured as follows. Section 2 provides a review of the literature on SSCM and collaboration theory. Section 3 introduces the method, and the empirical results are addressed in Section 4. Section 5 discusses the results and their managerial and theoretical implications. The final section includes concluding remarks and possible directions for future research related to SSCM.

2. Literature review

This section describes the background on SSCM, the concept of the collaboration theory and SSCM measurements. The proposed aspects and criteria will help formulate a framework to evaluate SSCM practices.

2.1 SSCM

Previous studies on logistics and SCM have examined issues such as the environment, safety and human rights in an isolated fashion without considering the potential interrelationships among them and other aspects of social responsibility (Carter and Jennings, 2002). Hence, Carter and Rogers (2008) introduced an SSCM framework of environmental, economic and social aspects that allow an organization to achieve long-term economic viability. Then, Carter and Easton (2011) reviewed 121 articles to develop a cogent agenda to guide SSCM research. Ahi and Searcy (2013) investigated the characteristics of business sustainability and SCM and proposed a new definition of SSCM: the creation of coordinated supply chains through the voluntary integration of economic, environmental and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information and capital flows associated with the procurement, production and distribution of products or services to meet stakeholder requirements and improve the profitability, competitiveness and resilience of the organization over the short and long term.

However, many studies have addressed the economic, environmental and social aspects as a complex combination by providing descriptions of industry practices but that lack a theoretical basis (Seuring and Müller, 2008). Several studies have noted that SSCM often lacks a theoretical background, and the theoretical framework of SSCM is still in its infancy (Svensson, 2007; Gold *et al.*, 2010). Thus, Liu *et al.* (2012) concluded that SSCM requires a multi-dimensional approach and argued that research on SSCM should be expanded to include other aspects because the triple bottom line cannot represent the entire SSCM framework. Subsequently, Ashby *et al.* (2012) and Hassini *et al.* (2012) conducted literature reviews to explore the different aspects of formulating a comprehensive framework to evaluate SSCM. Morali and Searcy (2013) found that those different aspects have generated extensive debate about the integration and practice of SCM. Brindley and Oxborrow (2014) extended the theoretical discussion on sustainable supply chains by providing empirical data based on real-life implementations and formulated an emergent aligned model of SSCM.

Accordingly, Pagell and Wu (2009) provided seven propositions for the study of SSCM to guide researchers to develop the theoretical basis. Hence, Wu and Pagell (2011) adopted the grounded theory-building approach to address the strategic trade-offs involved in SSCM decision making. Walker and Fones (2012) applied contingency theory to identify a variety of internal and external barriers within SSCM. Wolf (2014) applied the resource dependence theory to corporate sustainability performance to explore SSCM relationships; however, the study failed to clearly identify the connection between sustainability and SCM. Thus, this study proposes using collaboration theory to demonstrate the integration of sustainability and SCM. The following section describes the background of collaboration theory to illustrate SSCM interactions.

2.2 Collaboration theory

Gray (1985) defined collaboration as a process of joint decision making by key stakeholders about the future in relation to a problem domain. Jamal and Getz (1995) considered collaboration to be an inter-organizational process; however, it is very difficult for companies to put collaboration into SSCM practice and assess it under conditions of uncertainty. Thus, Lozano (2007) indicated that collaboration is a key element in problem solving to associate the dynamic interactions and incremental actions that can generate significant and continuing improvements that can lead organizations to become sustainable. To enhance the understanding of collaboration theory in SSCM practice, two main concepts must be addressed – congruence and alignment.

Doppelt (2010) described congruence as consistency among economic, environmental and social aspects that acts as a building block for long-term success on the path toward sustainability, whereas Lozano (2008) referred to alignment as the need/objective to be consistent within and throughout different organizational levels to avoid misunderstandings and conflicts. Failing to align efforts is akin to two people attempting to row a boat simultaneously: unaligned efforts lead to disorientation. To apply congruence, Myers (2004) defined the required degree of consistency in sustainability internalization to pass on the effects of sustainability to other aspects. Regarding the implementation of alignment, Hoof and Thiell (2014) described the intention to implement activities based on knowledge and recognition by undertaking the activities in accordance with that intention and supported by the firm's corresponding skills.

Lozano (2007, 2008) proposed that collaboration is a pathway to sustainability because it changes the paradigm from individual action to joint efforts for the achievement of common goals. Ageron *et al.* (2012) recognized that it is important to integrate collaboration into SSCM, which otherwise could result in a loss of competitive advantage and economic performance. Vlajic *et al.* (2012) considered collaboration to be a linkage between structural aspects and business processes in SSCM practice. Beske *et al.* (2014) emphasized joint development goals to collaboratively develop new technologies, processes and products that can transfer organizations' operations to the process levels of SSCM. Previous studies have applied the collaboration theory to views on joint development and cooperation to link to supply chain partners. Thus, this study applies collaboration theory as a theoretical basis and uses the IVTFNs-GRA method to demonstrate SSCM under informational and systemic insufficiency.

2.3 The proposed method

Seuring and Müller (2008) reviewed 191 studies that used statistical methods to explore the triggers for SSCM practice. Wu and Pagell (2011) adopted decision making under uncertainty to address the strategic trade-offs in SSCM. Liu *et al.* (2012) applied multi-dimensional integration to formulate a model for green market and SSCM integration based on qualitative data. Hassini *et al.* (2012) investigated 707 studies to propose an SSCM framework for performance evaluation using statistical methods. However, Büyüközkan and Çifçi (2013) noted that it is more difficult to assess performance with accurate quantitative evaluations due to their uncertain nature, and the authors therefore offered an analytical tool to perceive and prioritize quantitative and qualitative methods. Sometimes, a vague and imprecise (or even an incomplete) method is required.

In particular, experts and decision makers often find it difficult to indicate their opinion as a number between 0 and 1. Vahdani *et al.* (2013) noted that such an evaluation can be appropriated to present the degree of certainty based on an interval. Cornelis *et al.* (2006) revealed that several studies have argued that the presentation of linguistic expressions in the form of an ordinary fuzzy set is not adequately convincing and clear. Thus, Karnik and Mendel (2001) adopted the concept of interval-valued fuzzy sets to improve the linguistic modeling of a phenomenon. To enhance the quality of feasible alternatives, Baležentis and Zeng (2013) applied interval-valued fuzzy numbers to assess uncertainty in multi-criteria decision making. Although IVTFNs can overcome the barrier of incomplete information, it is essential in GRA to complete the systemic information for SSCM and assess decision making under uncertainty.

Zhai *et al.* (2009) defined GRA as an effective instrument that can assist decision making in uncertain situations and examine interactions with multiple-criteria for decision making. Deng (1989) and Chen and Ou (2009) indicated that GRA offers an influential evaluation model to assess the degree of each criterion based on the grade of its relationship within the system. Zhang *et al.* (2011) extended the GRA method to address multiple-criteria decision-making problems with IVTFNs and unknown information on criteria weights, which can provide a ranking of feasible alternatives and select the optimal solution (in practice, the two may frequently conflict). Thus, this study proposes using IVTFNs to address the lack-of-information problem and applies GRA to evaluate the interactions within criteria and to support the formulation of an SSCM framework.

2.4 The proposed SSCM measures

Prno and Scott Slocombe (2012) emphasized that economics (AS_1) plays a primary role in corporate decision making because of the profit motive that drives corporate actors in a free-market economy. Thus, a price strategy (C_1), asset use/utilization (C_2), enhanced customer service (C_3) and improvement in sales and market share (C_4) are considered necessary to increase economic sustainability (Wu and Pagell, 2011; Brindley and Oxborrow, 2014).

Matos and Hall (2007) noted that when making decisions about the environmental impact (AS_2) of their supply chains, companies face information uncertainty, evolving decision parameters and changing decision boundaries. Many companies have implemented environmental management systems (C_5), green innovation (C_6), environmental product design (C_7), waste reduction (C_8), environmental purchasing (C_9), recycling (C_{10}) and compliance with environmental standards (C_{11}) to avoid these uncertain conditions and confront the boundaries that interfere with the achievement of environmental sustainability (Hassini *et al.*, 2012; Gopalakrishnan *et al.*, 2012; Govindan *et al.*, 2014).

Although companies have strived to realize environmental sustainability, their efforts remain insufficient in the face of community pressure. The social aspect (AS_3) can assist companies in responding to such pressures, including employee practices (C_{12}), reduced community impacts (C_{13}), health and safety practices (C_{14}), laws and regulations (C_{15}), sustainable packaging (C_{16}), improvement in relations with community stakeholders (C_{17}) and the product image (C_{18}), which collectively relate to concerns about attaining social sustainability (Seuring and Müller, 2008; Liu *et al.*, 2012; Büyüközkan and Çifçi, 2013).

Dahlsrud (2008) noted that balancing stakeholders' often-conflicting concerns (AS_4) is a challenging task that depends on how companies interact with their employees, suppliers and customers. Sarkis *et al.* (2010) found a direct and positive relationship between stakeholder pressure and environmental practices. Thus, some research has emphasized addressing stakeholder needs through content forecast accuracy (C_{19}), supplier management (C_{20}), collaboration with partners (C_{21}), stakeholders' rights (C_{22}) and monitoring and maintenance (C_{23}) to create value and improve efficiency and overall performance in the supply chain (Ahi and Searcy, 2013; Büyüközkan and Çifçi, 2013).

Closs *et al.* (2011) and Ahi and Searcy (2013) have shown that resilience (AS_5) can address a diversity of needs and concerns of stakeholders and provide the flexibility to address multiple tasks in SSCM practice under uncertain conditions. Despite Closs *et al.*'s (2011) specification in previous research that the role of resilience in SSCM practice is limited, Büyüközkan and Çifçi (2013) have shown that resilience can be associated with flexible and cleaner technology (C_{24}) that can improve SSCM practice.

Subsequently, Violeta and Gheorghe (2009) revealed that companies employing planning-based integration tend to have long-term (AS_6) ambitions with respect to their commitment to developing a sustainable business. In other words, once a company can no longer generate long-term sustainability, it will lose the competition with its rivals.

Accordingly, some studies have proposed lifecycle management (C_{25}), the use of effective systems and tools (C_{26}), environmental capabilities (C_{27}) and reverse logistics (C_{28}) to maintain a company's long-term sustainability (Lu *et al.*, 2007; Badurdeen *et al.*, 2009; García-Rodríguez *et al.*, 2013).

Furthermore, Zailani *et al.* (2012) demonstrated empirical evidence of a strong integration between SSCM performance and operations (AS_7). Moreover, Brindley and Oxborrow (2014) highlighted that operations are the core aspect of the value proposition and must be aligned toward the SSCM function. These operations include inventory management (C_{29}), delivery performance (C_{30}), cost reduction (C_{31}), quality improvement (C_{32}), efficiency (C_{33}) and responsiveness (C_{34}).

Morali and Searcy (2013) stated there is an ongoing need for research that investigates the extent to which the interactions among the sustainability principles are integrated into SCM practices, particularly by considering SSCM through multiple aspects and criteria. Therefore, this study proposes aspects and criteria (see Table I) to

Aspects		Criteria	
AS_1	Economic	C_1	Price strategy
		C_2	Asset use/utilization
		C_3	Enhanced customer service
		C_4	Improvement in sales and market share
AS_2	Environmental	C_5	Environmental management system
		C_6	Green innovation
		C_7	Environmental product design
		C_8	Waste reduction
		C_9	Environmental purchasing
		C_{10}	Recycling
		C_{11}	Compliance with environmental standards
AS_3	Social	C_{12}	Employee practices
		C_{13}	Reduced impact on community
		C_{14}	Health and safety
		C_{15}	Laws and regulations
		C_{16}	Sustainable packaging
		C_{17}	Improvement in relations with community stakeholders and community activists
		C_{18}	Improvement in product image
AS_4	Stakeholder	C_{19}	Forecast accuracy
		C_{20}	Supplier management
		C_{21}	Collaboration with partners
		C_{22}	Stakeholders' rights
		C_{23}	Monitoring and maintenance
AS_5	Resilience	C_{24}	Flexible and cleaner technology
AS_6	Long term	C_{25}	Lifecycle management
		C_{26}	Usage of effective systems and tools
		C_{27}	Environmental activity capability
		C_{28}	Reverse logistics
AS_7	Operations	C_{29}	Inventory management
		C_{30}	Delivery performance
		C_{31}	Cost reduction
		C_{32}	Quality improvement
		C_{33}	Efficiency
		C_{34}	Responsiveness

Table I.
Proposed aspects and criteria

assess the performance of an SSCM practice and explores the clear interactions that support the SSCM theoretical framework. Through such an assessment, a decision maker can enhance SSCM performance under limited resources.

3. Methods

The following section presents the transformation from linguistic preference to quantitative data, the procedure for integrating IVTFNs with GRA and the proposed hybrid analytical steps.

3.1 Grey relationship analysis

Suppose a multi-criteria decision-making (MCDM) problem with m non-inferior criteria $C_1, C_2, \ldots, C_m$ and n aspects $A_1, A_2, \ldots, A_n$. Each criterion is evaluated with respect to the n aspects. All of the evaluated values/ratings are assigned to aspects related to the decision matrix denoted by $\tilde{R} = [\tilde{r}_{ij}]_{m \times n}$:

Definition 1. (Zhang *et al.*, 2011) To normalize the decision matrix, the first step must be to normalize value r_{ij} using the equations:

$$r_{ij} = \frac{x_{ij}}{\max(x_{ij})},\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n,\ \text{for}\ j \in I$$

$$r_{ij} = \frac{\min(x_{ij})}{x_{ij}},\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n,\ \text{for}\ j \in J$$

where I denotes the set of benefit criteria, and J represents the set of cost criteria. To determine the reference series R_0:

$$R_0 = \{r_{01}, r_{02}, \ldots, r_{0n}\},\ r_{0j} = \max_j r_{ij},\ j = 1,2,\ldots n.$$

Definition 2. (Chang *et al.*, 2011) The distance between two fuzzy numbers $\tilde{I} = (I_1, I_2, I_3)$ and $\tilde{J} = (J_1, J_2, J_3)$ is computed by:

$$\sigma\left(\tilde{I}, \tilde{J}\right) = \sqrt{\frac{1}{3}\left[(I_1 - J_1)^2 + (I_2 - J_2)^2 + (I_3 - J_3)^2\right]}$$

Definition 3. (Zhang and Liu, 2011) Establishment of the matrix. The δ_{ij} between the reference value and each comparison value is given as $\sigma_{ij} = r_{0j} - r_{ij}$.

Next, the matrix Δ can be obtained as:

$$\Delta = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1n} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2n} \\ \vdots & \vdots & & \vdots \\ \sigma_{m1} & \sigma_{m2} & \cdots & \sigma_{mn} \end{bmatrix}$$

Calculate the grey relational coefficient, δ_{ij}, which is defined as:

$$\delta_{ij} = \frac{\sigma_{min} + \xi\sigma_{max}}{\sigma_{ij} + \xi\sigma_{max}},\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n$$

where σ_{max} and σ_{min} are the maximum and minimum of σ_{ij} ($i=1, \ldots, m; j=1, \ldots, n$), respectively, and ξ is the distinguishing coefficient between 0 and 1. Usually, we suppose that ξ is 0.5.

Estimate the grey relational grade ι_i by the relation $\iota_i = \sum_{j=1}^{n} \omega_j \delta_{ij}, i = 1, 2, \ldots, m$ where ω_j is the weight of the jth criterion, and $\omega_j \geqslant 0$. $\sum_{j=1}^{n} \omega_j = 1$. Rank the criteria in accordance with the value of the grey relational grade. The larger the value of ι_i is, the better the criteria C_i is:

Definition 4. (Li *et al.*, 2009) The likelihood of $a \geqslant b$ for any two interval numbers a and b has some useful properties that are summarized as follows:

(a) $0 \leqslant p(a \geqslant b) \leqslant 1$;

(b) $p(a \geqslant b) + p(b \geqslant a) = 1$;

(c) $p(a \geqslant b) + p(b \geqslant a) = 0.5$ *if* $p(a \geqslant b) = p(b \geqslant a)$;

(d) $p(a \geqslant b) = 0$ *if* $a^+ \leqslant b^-$;

(e) For any interval numbers a, b and c, $p(a \geqslant c) = p(b \geqslant c)$ if $a \geqslant b$.

3.2 Interval-valued TFNs integrated with GRA

Consider a fuzzy MCDM problem; let $C = \{C_1, C_2, \ldots, C_m\}$ be a finite set of feasible criteria, and let $A = \{A_1, A_2, \ldots, A_n\}$ be a finite set of aspects. The weight vector of the criteria $\omega = (\omega_1, \omega_2, \ldots, \omega_n)$ is unknown, but it satisfies $w_j \geqslant 0$, $j = 1, 2, \ldots n$, $\sum_{j=1}^{n} w_j = 1$. Suppose that the performance of criteria C_i with respect to aspects A_j is denoted as $\tilde{x}_{ij}$, then $\tilde{X} = \left[\tilde{x}_{ij}\right]_{m \times n}$ is a fuzzy decision matrix.

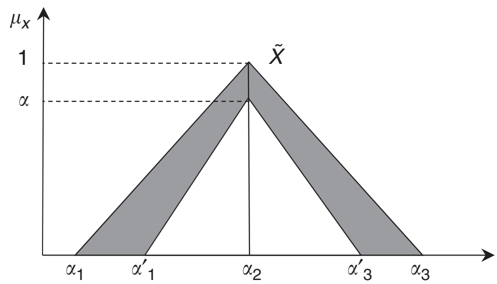
As shown in Figure 1, $\tilde{x}_{ij}$ can be expressed in IVTFNs $\tilde{x} = \{(a_1, a_2, a_3)(a_1', a_2, a_3')$. and can also be demonstrated as $[(a_1, a_1'); a_2; (a_3', a_3)]$.

Below, this study develops the GRA method integrated with IVTFN assessments, which can be described as follows.

Calculate the normalized decision matrix $\tilde{R}$. Here, simply denote $\tilde{r}_{ij} = [(a_{ij}, a_{ij}'); b_{ij}; (c_{ij}', c_{ij})]$, as shown in Table II. If the decision group has k respondents, the responses can be calculated as follows:

$$\tilde{r}_{ij} = \frac{1}{k}\left(\tilde{r}_{ij}^1 + \tilde{r}_{ij}^2 + \tilde{r}_{ij}^3 + \ldots + \tilde{r}_{ij}^k\right) = \frac{1}{k}\sum_{1}^{k} \tilde{r}_{ij}^k,$$

$$i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, t \qquad (1)$$



Source: Vahdani *et al.* (2013)

Figure 1. Interval-valued triangular fuzzy numbers

The normalized decision matrix $\tilde{R} = \left[\tilde{r}_{ij}\right]_{m \times n}$ can be obtained from the experts' responses. The normalized performance rating can be reformulated from Definition 1; then, show:

$$\tilde{r}_{ij} = \left[\left(\frac{a_{ij}}{c_j^+}, \frac{a'_{ij}}{c_j^+}\right); \frac{b_{ij}}{c_j^+}; \left(\frac{c'_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right)\right], \; i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n, \text{ for } j \in I \quad (2)$$

$$\tilde{r}_{ij} = \left[\left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{c'_{ij}}\right); \frac{a_j^-}{b_{ij}}; \left(\frac{a_j^-}{a'_{ij}}, \frac{a_j^-}{a_{ij}}\right)\right], \; i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n, \text{ for } j \in J \quad (3)$$

where $c_j^+ = \max_i\{c_{ij}, i = 1 \ldots m\}$ and $a_j^- = \min_i\{a_{ij}, i = 1 \ldots m\}$.

Therefore, the reference series can be obtained as follows:

$$R_0 = ([(1,1); 1; (1,1)], [(1,1); 1; (1,1)], \ldots, [(1,1); 1; (1,1)]) \quad (4)$$

Subsequently, the distance between the reference value and each comparison value can be computed based on Definition 2:

$$\sigma_{ij}^{(I)} = \sqrt{\frac{1}{3}\left[\left(\frac{a'_{ij}}{c_j^+} - 1\right)^2 + \left(\frac{b_{ij}}{c_j^+}\right) + \left(\frac{c_{ij}}{c_j^+} - 1\right)^2\right]},$$

$$\sigma_{ij}^{(I')} = \sqrt{\frac{1}{3}\left[\left(\frac{a_{ij}}{c_j^+} - 1\right)^2 + \left(\frac{b_{ij}}{c_j^+}\right) + \left(\frac{c'_{ij}}{c_j^+} - 1\right)^2\right]},$$

$$\sigma_{ij}^{(J)} = \sqrt{\frac{1}{3}\left[\left(\frac{a_j^-}{c'_{ij}} - 1\right)^2 + \left(\frac{a_j^-}{b_{ij}}\right) + \left(\frac{a_j^-}{a_{ij}} - 1\right)^2\right]},$$

$$\sigma_{ij}^{(J')} = \sqrt{\frac{1}{3}\left[\left(\frac{a_j^-}{c_{ij}} - 1\right)^2 + \left(\frac{a_j^-}{b_{ij}}\right) + \left(\frac{a_j^-}{a'_{ij}} - 1\right)^2\right]} \quad (5)$$

Linguistic variables	Interval-valued TFNs
Very poor (VP)	((0,0); 0; (0.1,0.15))
Poor (P)	((0,0.05); 0.1; (0.25,0.35))
Medium poor (MP)	((0,0.15); 0.3; (0.45,0.55))
Medium (M)	((0.25,0.35); 0.5; (0.55,0.65))
Medium good (MG)	((0.45,0.55); 0.7; (0.8,0.95))
Good (G)	((0.55,0.75); 0.9; (0.95,1))
Very good (VG)	((0.85,0.95); 1; (1,1))

Table II. Definitions of linguistic variables for the ratings

As a result of Definition 3, the distance between the reference value and each comparison value can be simplified as:

$$\begin{cases} \sigma_{ij}^{(1)} = \sigma_{ij}^{(I)} - \sigma_{ij}^{\left(I'\right)} \\ \sigma_{ij}^{(2)} = \sigma_{ij}^{(J)} - \sigma_{ij}^{\left(J'\right)} \end{cases} \tag{6}$$

The interval value $\overline{\sigma}_{ij} = [\sigma_{ij}^{(1)}, \sigma_{ij}^{(2)}]$ can be obtained. However, we must convert it into a crisp value due to a computed information loss. The maximum $\sigma_{max}^{(1)}, \sigma_{max}^{(2)}$ and minimum $\sigma_{min}^{(1)}, \sigma_{min}^{(2)}$ can be obtained as follows:

$$\begin{cases} \sigma_{\max}^{(1)} = \min_{ij}\sigma_{ij}^{(1)} \\ \sigma_{\max}^{(2)} = \min_{ij}\sigma_{ij}^{(2)} \\ \sigma_{\min}^{(1)} = \min_{ij}\sigma_{ij}^{(1)} \\ \sigma_{\min}^{(2)} = \min_{ij}\sigma_{ij}^{(2)} \end{cases}, \; i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n \tag{7}$$

Then, gather the grey relational coefficient:

$$\delta_{ij}^{(1)} = \frac{\sigma_{\min}^{(1)} + \xi\sigma_{\max}^{(1)}}{\sigma_{ij}^{(1)} + \xi\sigma_{\max}^{(1)}}, \; \delta_{ij}^{(2)} = \frac{\sigma_{\min}^{(2)} + \xi\sigma_{\max}^{(2)}}{\sigma_{ij}^{(2)} + \xi\sigma_{\max}^{(2)}}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{8}$$

Here, assume that ξ is 0.5.

To obtain $\iota_i^{(1)}$ and $\iota_i^{(2)}$, Zhang *et al.* (2011) proposed using the weight vector ω_j, $j = 1, 2, \ldots, n$, to normalize the data, as follows:

$$\omega_j = \frac{\sum_{i=1}^{m}\left(\delta_{ij}^{(1)} + \delta_{ij}^{(2)}\right)}{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\delta_{ij}^{(1)} + \delta_{ij}^{(2)}\right)} \tag{9}$$

Once $\omega_1, \omega_2, \ldots, \omega_n$ is gathered, we refer to the following equation to estimate the grey relational grade between the reference series and the comparison series, which we present as an interval value $\bar{\iota}_i = [\iota_i^{(1)}, \iota_i^{(2)}], i = 1, 2, \cdots m$:

$$\iota_i^{(1)} = \sum_{j=1}^{n}\omega_j\delta_{ij}^{(1)}, \; \iota_i^{(2)} = \sum_{j=1}^{n}\omega_j\delta_{ij}^{(2)}, \; i = 1, 2\ldots, m \tag{10}$$

Finally, the interval value must be converted into a weightage to calculate the ranking criteria. "Criteria C_s being not inferior to C_t" is denoted by $C_s \succcurlyeq C_t$. The likelihood of $C_s \succcurlyeq C_t$ is defined and measured by $\bar{\iota}_s \succcurlyeq \bar{\iota}_t$, where $\bar{\iota}_s$ and $\bar{\iota}_t$ are the corresponding grey relational grade interval numbers of criteria C_s and C_t in C, respectively (Li *et al.*, 2009). By transferring the interval value to use the concept of likelihood for the interval number, the likelihood $C_s \succcurlyeq C_t$ for criteria C_s and C_t in C can use the equation:

$$p(C_s \succcurlyeq C_t) = p(\bar{\iota}_s \succcurlyeq \bar{\iota}_t) = \max\left\{1 - \max\left\{\frac{\iota_i^{(1)} - \iota_i^{(2)}}{L(\bar{\iota}_s) + L(\bar{\iota}_t)}, 0\right\}, 0\right\} \quad (11)$$

where $\bar{\iota}_{i_s} = [\iota_s^{(1)}, \iota_s^{(2)}]$, $\bar{\iota}_{i_t} = [\iota_t^{(1)}, \iota_t^{(2)}]$, $L(\bar{\iota}_s) = \iota_s^{(2)} - \iota_s^{(1)}$, $L(\bar{\iota}_t) = \iota_t^{(2)} - \iota_t^{(1)}$

Thus, the likelihood matrix can be generated and rewritten using Definition 4(b) and (c) as follows:

$$P = (P_{st})_{m \times m} = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{pmatrix} P_{11} & P_{12} & \cdots & P_{1m} \\ P_{21} & P_{22} & \cdots & P_{2m} \\ \vdots & \vdots & & \vdots \\ P_{m1} & P_{m2} & \cdots & P_{mm} \end{pmatrix} \end{array} \quad (12)$$

where $P_{st} = p(C_s \succcurlyeq C_t), s, t = 1, 2, \ldots, m$ for criteria C_s and C_t in C. Accordingly, P is a complementary fuzzy judgment matrix (Zhang *et al.*, 2011), and the ranking weightage can be sorted from the vector $V_i(\mathrm{i} = 1, 2, \ldots, m)$ of P. The larger the value of V_i is, the more important is the criterion $C_i(i = 1, 2, \ldots, m)$

3.3 Proposed analytical procedures

This study attempts to apply IVTFNs and GRA to the evaluation of seven aspects and 34 criteria. The study's objective is to analyze how the proposed method can be used to determine SSCM interactions. An expert group followed the proposed solution using a four-step procedure. The procedures for the analysis can be explained as follows:

(1) Identification of the evaluating aspects and criteria. This step requires the formation of an expert committee based on group knowledge and experience to evaluate the interactions. The committee is asked to develop survey instruments and aspects and criteria for evaluation. The criteria have complicated relationships within a cluster of aspects and criteria.

(2) Computation of the range of the experts' opinions related to each criterion. At the beginning of this step, we use the IVTFNs in Table II to normalize the decision matrix into a performance rating. If the expert committee has different opinions about the decision, Equation (1) can help to obtain the average scores. Benefit and cost performance can be obtained by following Equations (2) and (3). Next, computation of the distance is needed to contrast the reference value using Equation (4), and then Equation (5) is used to obtain the distance value among the benefit and cost criteria.

(3) Gathering of the grey relational coefficient and transfer to the interval value. Once the distance value has been computed, it must be converted into a crisp value using Equation (6). However, there is some information loss during the conversion; thus, Equations (7)-(9) can assist in generating the grey relational coefficient to cover the information loss, and Equation (10) is used to transfer the grey relational coefficient into an interval value.

(4) Generation of the likelihood matrix and analysis of the weightage of the criteria is performed by applying Equation (11) to recognize the likelihood interaction

between each criterion. The likelihood matrix can be generated using Equation (12). Subsequently, the matrix is decomposed using MATLAB 10 to acquire the eigenvectors for each of the criteria. The criteria with the highest eigenvectors have the most influence on SSCM.

4. Results

In this section, there are seven aspects and 34 criteria encompassing SSCM that are evaluated using IVTFNs-GRA. The expert committee consists of two professors, one president, two vice presidents, two senior managers and one senior engineer, all of whom have comprehensive experience.

4.1 Case information

The studied company (Company T) is the largest specialized semiconductor manufacturer in Taiwan and is classified as a top-six semiconductor manufacturer worldwide. In addition, the Asian Corporate Governance Association selected Company T as number one in corporate governance among 864 corporations in the Asia-Pacific region, and the company's worldwide market share was 59 percent in 2014. Therefore, "zero defeat" is Company T's ultimate goal. If a customer has experienced a defective product, Company T uses a blockaded approach to defend the customer until the defect has been eliminated. The president of Company T has emphasized the duty to build a sustainable business to create a better future through seven aspects, including economic performance, environmental protection, social morality, stakeholders' rights (and the balancing of those rights), company flexibility, caring for the next generation over the long term and continuing to improve daily operations.

As a leading company in the area of sustainable development, Company T strives to establish itself as a benchmark for SSCM implementation in the industry. Company T has made huge investments and expended a large amount of resources to establish SSCM throughout the company and to encourage its supply chain partners to participate. However, Company T has faced challenges evaluating its performance after expanding its investment in SSCM. In other words, Company T lacks the ability to assess its practices and to determine the most effective practices for concentrating its investment. Hence, this study proposed SSCM aspects and criteria that match the principles emphasized by Company T's president and then determined the most influential practices that can allow Company T to improve its performance.

4.2 The results

(1) Responses from the experts were gathered to ensure the clear understanding of the relationships among the evaluating aspects and criteria. By consulting the expert committee, the information relevant to representing SSCM was confirmed. Each proposed aspect and criterion shown in Table I prompted discussion among the members of the expert committee, thus enhancing the study's validity and reliability. Once the experts raised an issue, a face-to-face interview was conducted for further clarification. To overcome the barriers caused by linguistic preferences and complicated interactions in the respondents' feedback, a hybrid method that integrates IVTFN with GRA was designed.

(2) The linguistic variables were converted into IVTFNs based on Table II. For example, "Medium (M)" is transformed into ((0.25,0.35);0.5;(0.55,0.65)). Equation (1) can assist in obtaining average scores from the diverse responses among the eight experts, as shown in Table III. Subsequently, Equations (2) and (3) are applied to obtain the benefit and cost criteria matrices.

(3) The distance range can be obtained from Equations (4) and (5). For example, $\delta^{I}_{C_1} = \sqrt{((0.401-1)^2+(0.510)^2+(0.650-1)^2)/3} = 0.497$ and $\delta^{I'}_{C_1} = \sqrt{((0.306-1)^2+(0.510)^2+(0.573-1)^2)/3} = 0.555$. Then, Equation (6) is used to generate the interval value $\sigma^{(1)}_{C_1} = 0.099$, and Equation (7) is applied to obtain $[\sigma^{(1)}_{min}\ \sigma^{(2)}_{min}] = [0.0000.000]$ and $[\sigma^{(1)}_{max}\sigma^{(2)}_{max}] = [0.180\ 0.192]$.

(4) Equation (8) is applied to transform the interval values into the grey relational coefficient. Furthermore, according to Equation (9), the weights are $\omega_1 = 0.0288$; $\omega_2 = 0.0308$; $\omega_3 = 0.0268;\ldots$; $\omega_{33} = 0.0313$; $\omega_{34} = 0.0312$. Next, we apply the collected weights into Equation (10), in which grey relational grades are formulated as the interval value: $\bar{\iota}_{AS_1} = [0.6090.682]$; $\bar{\iota}_{AS_2} = [0.6600.765]$; $\bar{\iota}_{AS_3} = [0.6240.780];\ldots;\bar{\iota}_{C_{33}} = [0.1410.192]$; $\bar{\iota}_{C_{34}} = [0.1560.175]$

(5) Based on Equation (11), the likelihood relationship of $AS_1 \geqslant AS_2$ can be calculated as follows:

$$p(AS_1 \succcurlyeq AS_2) = p\left(\bar{\iota}_{AS_1} \succcurlyeq \bar{\iota}_{AS_2}\right) = \max\left\{1-\max\left\{\frac{\iota^{(1)}_{i}-\iota^{(2)}_{i}}{L(\bar{\iota}_s)+L(\bar{\iota}_t)},0\right\},0\right\}$$

$$= \max\left\{1-\max\left\{\frac{(0.765-0.609)}{(0.682-0.609)+(0.765-0.660)},0\right\},0\right\} = 0.122$$

Afterward, the likelihood relationship can be arranged into a matrix using Equation (12), and the matrix is decomposed using MATLAB 10 to obtain the eigenvectors. Higher eigenvectors have more influential effects in the SSCM practice.

Table IV expresses the likelihood matrix of the aspects, which includes seven eigenvectors – 0.149, 0.338, 0.320, 0.352, 0.340, 0.337 and 0.639, respectively. Thus, the likelihood relationship for the SSCM aspects can interpreted as $AS_7 \geqslant AS_4 \geqslant AS_5 \geqslant AS_2 \geqslant AS_6 \geqslant AS_3 \geqslant AS_1$. This result reveals that operations (AS_7) is the highest priority for the company to focus on, followed by stakeholders (AS_4) and resilience (AS_5).

Table V shows that the top five influential criteria are improvement in supplier management (C_{20}), flexible and cleaner technology (C_{24}), responsiveness (C_{34}), compliance with environmental standards (C_{11}) and efficiency (C_{33}). The criteria can be ranked as follows $C_{20} \geqslant C_{24} \geqslant C_{34} \geqslant C_{11} \geqslant C_{33} \geqslant C_9 \geqslant C_{22} \geqslant C_2 \geqslant C_6 \geqslant C_{16} \geqslant C_{30} \geqslant C_{12} \geqslant C_7 \geqslant C_{29} \geqslant C_8 \geqslant C_{15} \geqslant C_4 \geqslant C_{27} \geqslant C_{28} \geqslant C_{23} \geqslant C_{25} \geqslant C_1 \geqslant C_{32} \geqslant C_{31} \geqslant C_{18} \geqslant C_{21} \geqslant C_{13} \geqslant C_5 \geqslant C_{10} \geqslant C_{17} \geqslant C_{14} \geqslant C_{26} \geqslant C_{19} \geqslant C_3$. These results provide significant evidence and a quantitative basis for Company T to understand its current SSCM practice.

5. Theoretical implications

Although Ahi and Searcy (2013) divided SSCM into business sustainability and SCM to clarify its definitions and potential aspects through a literature review, operations are still absent from the discussion. However, many studies have specified that operations are a core aspect by demonstrating the direct impact of regulations, stakeholder pressure,

Table III. Responses from experts

	AS_1 a_{ij}	a'_{ij}	b_{ij}	c'_{ij}	c_{ij}	AS_2 a_{ij}	a'_{ij}	b_{ij}	c'_{ij}	c_{ij}	AS_3 a_{ij}	a'_{ij}	b_{ij}	c'_{ij}	c_{ij}	AS_4 a_{ij}	a'_{ij}	b_{ij}	c'_{ij}	c_{ij}
C_1	0.300	0.394	0.500	0.563	0.638	0.388	0.506	0.625	0.700	0.781	0.206	0.281	0.350	0.438	0.500	0.200	0.269	0.350	0.425	0.494
C_2	0.494	0.575	0.625	0.675	0.706	0.419	0.506	0.575	0.638	0.688	0.413	0.538	0.663	0.750	0.844	0.475	0.625	0.750	0.819	0.881
C_3	0.156	0.250	0.350	0.456	0.544	0.100	0.181	0.263	0.369	0.444	0.088	0.175	0.275	0.394	0.488	0.425	0.519	0.588	0.656	0.700
C_4	0.419	0.519	0.600	0.663	0.713	0.444	0.575	0.713	0.788	0.881	0.250	0.338	0.438	0.544	0.644	0.406	0.538	0.650	0.731	0.800
C_5	0.300	0.363	0.425	0.506	0.575	0.194	0.269	0.350	0.456	0.544	0.069	0.138	0.200	0.313	0.381	0.481	0.588	0.700	0.769	0.856
C_6	0.338	0.450	0.550	0.644	0.719	0.188	0.275	0.375	0.469	0.556	0.300	0.363	0.425	0.506	0.575	0.281	0.350	0.438	0.519	0.606
C_7	0.525	0.613	0.675	0.713	0.744	0.206	0.331	0.438	0.544	0.619	0.369	0.450	0.525	0.594	0.656	0.156	0.263	0.375	0.481	0.569
C_8	0.306	0.400	0.500	0.594	0.688	0.481	0.600	0.725	0.794	0.881	0.406	0.519	0.613	0.688	0.750	0.275	0.400	0.513	0.606	0.681
C_9	0.238	0.313	0.388	0.469	0.538	0.344	0.463	0.575	0.650	0.719	0.513	0.650	0.763	0.825	0.881	0.313	0.450	0.563	0.656	0.725
C_{10}	0.156	0.288	0.425	0.544	0.644	0.338	0.450	0.550	0.644	0.719	0.338	0.463	0.600	0.694	0.800	0.400	0.519	0.625	0.694	0.763
C_{11}	0.250	0.338	0.450	0.519	0.606	0.256	0.350	0.450	0.531	0.613	0.394	0.488	0.613	0.694	0.806	0.300	0.388	0.475	0.569	0.650
C_{12}	0.238	0.369	0.488	0.581	0.656	0.331	0.425	0.513	0.588	0.656	0.319	0.413	0.513	0.594	0.675	0.306	0.431	0.563	0.663	0.763
C_{13}	0.238	0.325	0.413	0.494	0.563	0.106	0.188	0.263	0.381	0.456	0.281	0.394	0.488	0.581	0.644	0.469	0.563	0.675	0.750	0.850
C_{14}	0.106	0.150	0.188	0.306	0.381	0.363	0.500	0.638	0.713	0.794	0.269	0.363	0.475	0.569	0.669	0.231	0.350	0.463	0.575	0.663
C_{15}	0.088	0.169	0.263	0.388	0.488	0.281	0.381	0.500	0.588	0.681	0.381	0.463	0.550	0.631	0.713	0.406	0.494	0.575	0.644	0.706
C_{16}	0.200	0.288	0.375	0.463	0.538	0.294	0.394	0.500	0.581	0.663	0.431	0.538	0.650	0.706	0.781	0.275	0.356	0.425	0.500	0.556
C_{17}	0.144	0.238	0.350	0.475	0.588	0.244	0.350	0.438	0.531	0.594	0.163	0.231	0.300	0.419	0.506	0.294	0.381	0.475	0.556	0.638
C_{18}	0.288	0.363	0.438	0.531	0.613	0.331	0.444	0.550	0.631	0.706	0.206	0.300	0.425	0.525	0.638	0.281	0.363	0.463	0.544	0.631
C_{19}	0.306	0.381	0.475	0.569	0.669	0.063	0.163	0.275	0.388	0.475	0.281	0.400	0.525	0.625	0.725	0.438	0.556	0.663	0.725	0.788
C_{20}	0.431	0.563	0.688	0.750	0.825	0.369	0.475	0.575	0.656	0.731	0.538	0.638	0.725	0.788	0.850	0.344	0.475	0.588	0.669	0.738
C_{21}	0.306	0.438	0.575	0.681	0.788	0.200	0.325	0.450	0.550	0.638	0.281	0.369	0.438	0.531	0.594	0.356	0.463	0.575	0.663	0.750
C_{22}	0.250	0.325	0.413	0.506	0.594	0.281	0.363	0.463	0.556	0.656	0.275	0.369	0.475	0.581	0.681	0.300	0.381	0.450	0.531	0.594
C_{23}	0.294	0.425	0.563	0.650	0.738	0.344	0.444	0.538	0.606	0.669	0.063	0.169	0.288	0.406	0.500	0.275	0.363	0.450	0.525	0.588
C_{24}	0.225	0.325	0.438	0.538	0.631	0.419	0.538	0.663	0.731	0.819	0.581	0.681	0.763	0.800	0.844	0.438	0.563	0.675	0.744	0.813
C_{25}	0.275	0.394	0.500	0.588	0.656	0.231	0.325	0.413	0.513	0.588	0.219	0.306	0.400	0.513	0.606	0.256	0.344	0.450	0.531	0.619
C_{26}	0.100	0.194	0.288	0.394	0.469	0.256	0.338	0.438	0.513	0.594	0.206	0.269	0.363	0.444	0.538	0.225	0.294	0.375	0.469	0.556
C_{27}	0.325	0.419	0.525	0.594	0.675	0.463	0.538	0.613	0.669	0.731	0.319	0.413	0.513	0.594	0.675	0.400	0.506	0.613	0.675	0.744
C_{28}	0.369	0.525	0.663	0.750	0.825	0.263	0.375	0.475	0.569	0.644	0.350	0.444	0.513	0.581	0.625	0.275	0.350	0.438	0.538	0.631
C_{29}	0.138	0.219	0.300	0.413	0.494	0.356	0.456	0.563	0.644	0.725	0.456	0.575	0.700	0.763	0.844	0.363	0.488	0.613	0.688	0.769
C_{30}	0.194	0.250	0.313	0.400	0.469	0.388	0.513	0.613	0.694	0.750	0.325	0.406	0.488	0.581	0.663	0.375	0.469	0.575	0.656	0.750
C_{31}	0.231	0.306	0.413	0.513	0.625	0.313	0.438	0.575	0.663	0.763	0.300	0.375	0.450	0.531	0.600	0.331	0.438	0.538	0.625	0.706
C_{32}	0.419	0.544	0.638	0.706	0.756	0.269	0.350	0.450	0.544	0.644	0.188	0.256	0.338	0.425	0.506	0.219	0.294	0.375	0.475	0.556
C_{33}	0.394	0.500	0.600	0.688	0.769	0.425	0.519	0.613	0.681	0.756	0.363	0.500	0.625	0.706	0.788	0.350	0.444	0.525	0.600	0.656
C_{34}	0.400	0.519	0.625	0.694	0.763	0.163	0.269	0.388	0.481	0.569	0.450	0.563	0.663	0.719	0.775	0.313	0.419	0.538	0.619	0.713

(*continued*)

	AS5					AS6					AS7				
	a_{ij}	a'_{ij}	b_{ij}	c'_{ij}	c_{ij}	a_{ij}	a'_{ij}	b_{ij}	c'_{ij}	c_{ij}	a_{ij}	a'_{ij}	b_{ij}	c'_{ij}	c_{ij}
C_1	0.269	0.331	0.388	0.475	0.538	0.331	0.444	0.550	0.631	0.706	0.450	0.550	0.638	0.694	0.750
C_2	0.206	0.300	0.388	0.481	0.550	0.363	0.488	0.613	0.688	0.769	0.494	0.613	0.725	0.788	0.863
C_3	0.288	0.369	0.450	0.550	0.638	0.231	0.306	0.375	0.469	0.538	0.356	0.431	0.538	0.631	0.719
C_4	0.269	0.356	0.463	0.563	0.669	0.219	0.313	0.413	0.519	0.606	0.281	0.294	0.400	0.513	0.588
C_5	0.338	0.413	0.525	0.625	0.750	0.163	0.206	0.250	0.356	0.431	0.544	0.575	0.700	0.769	0.838
C_6	0.400	0.531	0.650	0.719	0.788	0.281	0.350	0.438	0.519	0.606	0.438	0.469	0.575	0.644	0.719
C_7	0.381	0.475	0.575	0.669	0.763	0.256	0.375	0.500	0.594	0.688	0.225	0.181	0.263	0.363	0.450
C_8	0.369	0.475	0.575	0.656	0.731	0.319	0.425	0.525	0.613	0.694	0.350	0.381	0.500	0.600	0.669
C_9	0.438	0.538	0.625	0.681	0.738	0.356	0.488	0.625	0.694	0.781	0.306	0.363	0.463	0.531	0.600
C_{10}	0.175	0.250	0.350	0.450	0.550	0.300	0.381	0.450	0.531	0.594	0.319	0.400	0.550	0.619	0.719
C_{11}	0.263	0.331	0.400	0.481	0.550	0.369	0.481	0.613	0.688	0.788	0.338	0.369	0.450	0.538	0.613
C_{12}	0.313	0.406	0.488	0.569	0.631	0.325	0.438	0.563	0.638	0.725	0.456	0.469	0.563	0.644	0.700
C_{13}	0.375	0.469	0.575	0.656	0.750	0.406	0.525	0.663	0.738	0.838	0.431	0.575	0.713	0.775	0.850
C_{14}	0.238	0.338	0.438	0.519	0.588	0.313	0.438	0.538	0.631	0.700	0.331	0.375	0.525	0.631	0.725
C_{15}	0.225	0.306	0.400	0.494	0.581	0.425	0.538	0.638	0.706	0.775	0.338	0.344	0.463	0.544	0.625
C_{16}	0.225	0.331	0.438	0.538	0.625	0.213	0.294	0.388	0.481	0.569	0.331	0.350	0.488	0.588	0.681
C_{17}	0.356	0.463	0.575	0.663	0.750	0.375	0.481	0.600	0.681	0.775	0.313	0.406	0.488	0.569	0.631
C_{18}	0.375	0.469	0.550	0.631	0.694	0.113	0.175	0.250	0.375	0.475	0.294	0.300	0.400	0.481	0.569
C_{19}	0.338	0.463	0.575	0.669	0.744	0.294	0.406	0.538	0.594	0.675	0.250	0.300	0.400	0.500	0.594
C_{20}	0.356	0.475	0.588	0.681	0.769	0.438	0.525	0.613	0.675	0.744	0.375	0.369	0.475	0.550	0.625
C_{21}	0.306	0.425	0.563	0.663	0.769	0.469	0.588	0.713	0.794	0.894	0.275	0.369	0.463	0.544	0.613
C_{22}	0.338	0.475	0.613	0.681	0.756	0.538	0.638	0.725	0.788	0.850	0.294	0.275	0.375	0.481	0.581
C_{23}	0.438	0.575	0.725	0.794	0.894	0.444	0.575	0.700	0.750	0.813	0.369	0.350	0.438	0.525	0.600
C_{24}	0.325	0.431	0.538	0.631	0.713	0.238	0.325	0.425	0.531	0.631	0.225	0.213	0.325	0.431	0.525
C_{25}	0.369	0.475	0.563	0.638	0.700	0.338	0.431	0.550	0.631	0.731	0.406	0.481	0.600	0.688	0.769
C_{26}	0.144	0.219	0.313	0.431	0.538	0.275	0.375	0.500	0.588	0.694	0.319	0.325	0.450	0.563	0.669
C_{27}	0.306	0.438	0.550	0.638	0.713	0.144	0.219	0.313	0.419	0.513	0.344	0.363	0.488	0.581	0.663
C_{28}	0.213	0.319	0.438	0.544	0.644	0.306	0.419	0.538	0.638	0.738	0.175	0.181	0.288	0.419	0.506
C_{29}	0.281	0.375	0.488	0.581	0.681	0.344	0.438	0.525	0.588	0.644	0.381	0.425	0.538	0.619	0.694
C_{30}	0.269	0.325	0.375	0.456	0.513	0.350	0.413	0.463	0.531	0.581	0.275	0.300	0.400	0.488	0.563
C_{31}	0.319	0.456	0.588	0.681	0.769	0.306	0.394	0.488	0.556	0.625	0.288	0.363	0.475	0.575	0.663
C_{32}	0.275	0.381	0.475	0.563	0.631	0.294	0.400	0.500	0.581	0.656	0.606	0.625	0.738	0.806	0.875
C_{33}	0.556	0.663	0.750	0.788	0.831	0.331	0.481	0.613	0.700	0.775	0.269	0.263	0.363	0.488	0.581
C_{34}	0.663	0.775	0.875	0.919	0.981	0.513	0.631	0.725	0.781	0.831	0.463	0.425	0.500	0.575	0.650

Table III.

resource depletion and corporate social responsibility on operational processes that involve SSCM (Delbard, 2008; Gold *et al.*, 2013; Brindley and Oxborrow, 2014). These findings support the argument that operations are the most important aspect. In SSCM development, operations have to considered through responsiveness and efficiency performance, which must be exhibited even under radical environment changes.

There is an ongoing need for research that investigates the extent to which interactions related to corporate sustainability principles are integrated into SCM practices that are constructed on a theoretical basis (Brandenburg *et al.*, 2014). The results offer a significant basis for theory development, which needs to consider stakeholder aspects in SSCM. Most companies desire to adopt SSCM, but supplier management is a critical issue in the stakeholder aspect. Companies may need to involve SCM to attain sustainability because not all suppliers have enough technology to reduce or prevent environmental impacts during production. These findings reveal significant support for the argument that it is insufficient to address SSCM exclusively through economic, environmental and social aspects. Instead, sustainability and SCM aspects should be addressed simultaneously to cover all of the SSCM principles.

Therefore, a company must develop the ability to be resilient – to adjust easily under uncertain conditions – for sustainability to be achieved along the entire supply chain. Although resilience has not been addressed in previous studies (Brand, 2009; Closs *et al.*, 2011), the results show significant evidence that resilience is an important aspect of SSCM. Several studies have suggested that companies can achieve resilience by developing flexible and cleaner technologies that offer more efficient utilization of natural resources and by designing reused or recycled products (Lu *et al.*, 2007; Vachon and Mao, 2008). Once a company exhibits enough resilience, it will be sufficiently competitive to address diverse sustainability campaigns.

Unlike many previous studies that have focused on the economic, environmental and social aspects of sustainability, this study explored interactions among extended aspects of SSCM. The proposal to use collaboration theory illustrates the integration of sustainability and SCM by offering a significant theoretical basis to complement the gaps generated by previous studies and by enhancing the knowledge and understanding of SSCM. Therefore, the aspects of SCM should be the priority consideration over sustainability. Once operations, stakeholders and resilience are aligned, it will be easy for a company to comply with environmental requirements/regulations to achieve sustainability. Although most people would assume that the economic, environmental and social aspects are the most important in current practice, the critical aspects involved in SSCM are operations, stakeholders and resilience, which refer to the alignment of SCM (Carter and Rogers, 2008; Seuring and Müller, 2008; Zailani *et al.*, 2012; Gold *et al.*, 2013; Ahi and Searcy, 2013).

Table IV.
Likelihood matrix and ranking for aspects

	AS_1	AS_2	AS_3	AS_4	AS_5	AS_6	AS_7	Eigenvector	Ranking
AS_1	0.500	0.122	0.254	0.246	0.255	0.258	0.000	0.149	7
AS_2	0.878	0.500	0.542	0.502	0.518	0.522	0.053	0.338	4
AS_3	0.746	0.458	0.500	0.471	0.483	0.486	0.092	0.320	6
AS_4	0.754	0.498	0.529	0.500	0.512	0.515	0.162	0.352	2
AS_5	0.745	0.482	0.517	0.488	0.500	0.503	0.140	0.340	3
AS_6	0.742	0.478	0.514	0.485	0.497	0.500	0.136	0.337	5
AS_7	1.000	0.947	0.908	0.838	0.860	0.864	0.500	0.639	1

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C17	C18
C_1	0.500	0.254	0.851	0.429	0.525	0.286	0.240	0.390	0.184	0.627	0.145	0.369	0.503	0.755	0.333	0.298	0.671	0.533
C_2	0.746	0.500	1.000	0.660	0.843	0.610	0.680	0.630	0.479	0.892	0.417	0.613	0.840	1.000	0.658	0.620	0.931	0.791
C_3	0.149	0.000	0.500	0.086	0.006	0.000	0.000	0.013	0.000	0.284	0.000	0.000	0.000	0.430	0.000	0.000	0.358	0.168
C_4	0.571	0.340	0.914	0.500	0.613	0.395	0.391	0.466	0.291	0.694	0.246	0.447	0.598	0.818	0.439	0.406	0.734	0.605
C_5	0.475	0.157	0.994	0.387	0.500	0.155	0.000	0.334	0.035	0.644	0.000	0.306	0.465	0.828	0.223	0.174	0.703	0.518
C_6	0.714	0.390	1.000	0.605	0.845	0.500	0.556	0.563	0.331	0.913	0.263	0.539	0.841	1.000	0.570	0.516	0.967	0.773
C_7	0.760	0.320	1.000	0.609	1.000	0.444	0.500	0.553	0.206	1.000	0.130	0.520	1.000	1.000	0.557	0.470	1.000	0.847
C_8	0.610	0.370	0.987	0.534	0.666	0.437	0.447	0.500	0.325	0.742	0.275	0.481	0.653	0.876	0.484	0.448	0.783	0.647
C_9	0.816	0.521	1.000	0.709	0.965	0.669	0.794	0.675	0.500	1.000	0.423	0.656	0.971	1.000	0.730	0.682	1.000	0.874
C_{10}	0.373	0.108	0.716	0.306	0.356	0.087	0.000	0.258	0.000	0.500	0.000	0.233	0.319	0.630	0.139	0.102	0.551	0.402
C_{11}	0.855	0.583	1.000	0.754	1.000	0.737	0.870	0.725	0.577	1.000	0.500	0.707	1.000	1.000	0.792	0.748	1.000	0.911
C_{12}	0.631	0.387	1.000	0.553	0.694	0.461	0.480	0.519	0.344	0.767	0.293	0.500	0.683	0.907	0.509	0.472	0.808	0.670
C_{13}	0.497	0.160	1.000	0.402	0.535	0.159	0.000	0.347	0.029	0.681	0.000	0.317	0.500	0.886	0.233	0.179	0.744	0.544
C_{14}	0.245	0.000	0.570	0.182	0.172	0.000	0.000	0.124	0.000	0.370	0.000	0.093	0.114	0.500	0.000	0.000	0.430	0.268
C_{15}	0.667	0.342	1.000	0.561	0.777	0.430	0.443	0.516	0.270	0.861	0.208	0.491	0.767	1.000	0.500	0.446	0.916	0.723
C_{16}	0.702	0.380	1.000	0.594	0.826	0.484	0.530	0.552	0.318	0.898	0.252	0.528	0.821	1.000	0.554	0.500	0.952	0.760
C_{17}	0.329	0.069	0.642	0.266	0.297	0.033	0.000	0.217	0.000	0.449	0.000	0.192	0.256	0.570	0.084	0.048	0.500	0.355
C_{18}	0.467	0.209	0.832	0.395	0.482	0.227	0.153	0.353	0.126	0.598	0.089	0.330	0.456	0.732	0.277	0.240	0.645	0.500
C_{19}	0.168	0.000	0.621	0.097	0.011	0.000	0.000	0.016	0.000	0.326	0.000	0.000	0.000	0.505	0.000	0.000	0.409	0.192
C_{20}	1.000	0.759	1.000	0.920	1.000	0.974	1.000	0.898	0.789	1.000	0.694	0.883	1.000	1.000	1.000	0.983	1.000	1.000
C_{21}	0.465	0.191	0.866	0.389	0.482	0.203	0.108	0.344	0.097	0.606	0.061	0.319	0.452	0.752	0.258	0.217	0.656	0.501
C_{22}	0.749	0.505	1.000	0.664	0.846	0.615	0.686	0.634	0.485	0.895	0.422	0.617	0.844	1.000	0.663	0.625	0.933	0.794
C_{23}	0.525	0.287	0.868	0.455	0.556	0.328	0.300	0.418	0.226	0.649	0.185	0.398	0.537	0.774	0.373	0.339	0.691	0.558
C_{24}	0.932	0.619	1.000	0.810	1.000	0.819	1.000	0.780	0.620	1.000	0.527	0.761	1.000	1.000	0.886	0.832	1.000	1.000
C_{25}	0.511	0.263	0.871	0.439	0.540	0.299	0.257	0.400	0.195	0.640	0.154	0.379	0.518	0.771	0.347	0.311	0.684	0.545
C_{26}	0.222	0.000	0.582	0.156	0.129	0.000	0.000	0.092	0.000	0.357	0.000	0.058	0.058	0.501	0.000	0.000	0.423	0.246
C_{27}	0.555	0.312	0.923	0.482	0.596	0.362	0.345	0.445	0.254	0.685	0.209	0.425	0.579	0.818	0.409	0.373	0.728	0.591
C_{28}	0.564	0.278	1.000	0.478	0.619	0.327	0.287	0.435	0.201	0.721	0.153	0.411	0.598	0.888	0.385	0.341	0.772	0.607
C_{29}	0.659	0.358	1.000	0.561	0.755	0.444	0.463	0.520	0.296	0.836	0.236	0.497	0.745	1.000	0.507	0.459	0.887	0.710
C_{30}	0.658	0.382	1.000	0.568	0.742	0.468	0.493	0.531	0.332	0.817	0.275	0.509	0.732	0.985	0.523	0.480	0.863	0.704
C_{31}	0.484	0.237	0.831	0.414	0.504	0.263	0.209	0.374	0.164	0.610	0.126	0.352	0.480	0.737	0.311	0.276	0.654	0.516
C_{32}	0.523	0.242	0.963	0.441	0.560	0.275	0.212	0.397	0.158	0.672	0.115	0.373	0.536	0.830	0.332	0.289	0.723	0.562
C_{33}	0.786	0.563	1.000	0.706	0.881	0.677	0.755	0.680	0.555	0.920	0.493	0.665	0.881	1.000	0.720	0.686	0.955	0.828
C_{34}	0.916	0.573	1.000	0.785	1.000	0.780	1.000	0.750	0.562	1.000	0.465	0.728	1.000	1.000	0.857	0.795	1.000	0.992

(continued)

Table V. Likelihood matrix and ranking for criteria

Table V.

	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}	Eigen vector	Ranking
C_1	0.832	0.000	0.535	0.251	0.475	0.068	0.489	0.778	0.445	0.436	0.341	0.342	0.516	0.477	0.214	0.084	0.120	22
C_2	1.000	0.241	0.809	0.495	0.713	0.381	0.737	1.000	0.688	0.722	0.642	0.618	0.763	0.758	0.437	0.427	0.227	8
C_3	0.379	0.000	0.134	0.000	0.132	0.000	0.129	0.418	0.077	0.000	0.000	0.000	0.169	0.037	0.000	0.000	0.016	34
C_4	0.903	0.080	0.611	0.336	0.545	0.190	0.561	0.844	0.518	0.522	0.439	0.432	0.586	0.559	0.294	0.215	0.155	17
C_5	0.989	0.000	0.518	0.154	0.444	0.000	0.460	0.871	0.404	0.381	0.245	0.258	0.496	0.440	0.119	0.000	0.091	28
C_6	1.000	0.026	0.797	0.385	0.672	0.181	0.701	1.000	0.638	0.673	0.556	0.532	0.737	0.725	0.323	0.220	0.189	9
C_7	1.000	0.000	0.892	0.314	0.700	0.000	0.743	1.000	0.655	0.713	0.537	0.507	0.791	0.788	0.245	0.000	0.174	13
C_8	0.984	0.102	0.656	0.366	0.582	0.220	0.600	0.908	0.555	0.565	0.480	0.469	0.626	0.603	0.320	0.250	0.170	15
C_9	1.000	0.211	0.903	0.515	0.774	0.380	0.805	1.000	0.746	0.799	0.704	0.668	0.836	0.842	0.445	0.438	0.244	6
C_{10}	0.674	0.000	0.394	0.105	0.351	0.000	0.360	0.643	0.315	0.279	0.164	0.183	0.390	0.328	0.080	0.000	0.067	29
C_{11}	1.000	0.306	0.939	0.578	0.815	0.473	0.846	1.000	0.791	0.847	0.764	0.725	0.874	0.885	0.507	0.535	0.268	4
C_{12}	1.000	0.117	0.681	0.383	0.602	0.239	0.621	0.942	0.575	0.589	0.503	0.491	0.648	0.627	0.335	0.272	0.178	12
C_{13}	1.000	0.000	0.548	0.156	0.463	0.000	0.482	0.942	0.421	0.402	0.255	0.268	0.520	0.464	0.119	0.000	0.095	27
C_{14}	0.495	0.000	0.248	0.000	0.226	0.000	0.229	0.499	0.182	0.112	0.000	0.015	0.263	0.170	0.000	0.000	0.032	31
C_{15}	1.000	0.000	0.742	0.337	0.627	0.114	0.653	1.000	0.591	0.615	0.493	0.477	0.689	0.668	0.280	0.143	0.167	16
C_{16}	1.000	0.017	0.783	0.375	0.661	0.168	0.689	1.000	0.627	0.659	0.541	0.520	0.724	0.711	0.314	0.205	0.184	10
C_{17}	0.591	0.000	0.344	0.067	0.309	0.000	0.316	0.577	0.272	0.228	0.113	0.137	0.346	0.277	0.045	0.000	0.054	30
C_{18}	0.808	0.000	0.499	0.206	0.442	0.000	0.455	0.754	0.409	0.393	0.290	0.296	0.484	0.438	0.172	0.008	0.102	25
C_{19}	0.500	0.000	0.155	0.000	0.148	0.000	0.146	0.505	0.088	0.000	0.000	0.000	0.191	0.045	0.000	0.000	0.018	33
C_{20}	1.000	0.500	1.000	0.752	0.988	0.697	1.000	1.000	0.968	1.000	0.983	0.925	1.000	1.000	0.665	0.782	0.333	1
C_{21}	0.845	0.000	0.500	0.188	0.439	0.000	0.452	0.779	0.404	0.385	0.273	0.281	0.483	0.434	0.153	0.000	0.097	26
C_{22}	1.000	0.248	0.812	0.500	0.716	0.388	0.740	1.000	0.692	0.726	0.647	0.622	0.766	0.761	0.442	0.434	0.229	7
C_{23}	0.852	0.012	0.561	0.284	0.500	0.117	0.514	0.797	0.471	0.467	0.378	0.376	0.540	0.507	0.245	0.137	0.133	20
C_{24}	1.000	0.303	1.000	0.612	0.883	0.500	0.922	1.000	0.857	0.937	0.844	0.790	0.954	0.981	0.529	0.578	0.287	2
C_{25}	0.854	0.000	0.548	0.260	0.486	0.078	0.500	0.796	0.455	0.448	0.353	0.353	0.527	0.490	0.222	0.095	0.124	21
C_{26}	0.495	0.000	0.221	0.000	0.203	0.000	0.204	0.500	0.154	0.069	0.000	0.000	0.241	0.134	0.000	0.000	0.027	32
C_{27}	0.912	0.032	0.596	0.308	0.529	0.143	0.545	0.846	0.500	0.501	0.411	0.406	0.572	0.541	0.266	0.166	0.144	18
C_{28}	1.000	0.000	0.615	0.274	0.533	0.063	0.552	0.931	0.499	0.500	0.389	0.386	0.583	0.548	0.230	0.081	0.135	19
C_{29}	1.000	0.017	0.727	0.353	0.622	0.156	0.647	1.000	0.589	0.611	0.500	0.484	0.680	0.659	0.298	0.189	0.171	14
C_{30}	1.000	0.075	0.719	0.378	0.624	0.210	0.647	1.000	0.594	0.614	0.516	0.500	0.677	0.658	0.325	0.244	0.180	11
C_{31}	0.809	0.000	0.517	0.234	0.460	0.046	0.473	0.759	0.428	0.417	0.320	0.323	0.500	0.459	0.198	0.059	0.112	24
C_{32}	0.955	0.000	0.566	0.239	0.493	0.019	0.510	0.866	0.459	0.452	0.341	0.342	0.541	0.500	0.198	0.033	0.119	23
C_{33}	1.000	0.335	0.847	0.558	0.755	0.471	0.778	1.000	0.734	0.770	0.702	0.675	0.802	0.802	0.500	0.519	0.251	5
C_{34}	1.000	0.218	1.000	0.566	0.863	0.422	0.905	1.000	0.834	0.919	0.811	0.756	0.941	0.967	0.481	0.500	0.273	3

6. Managerial implications

The empirical results reveal that supplier management should be considered the top priority in achieving sustainability for the entire supply chain. The studied company showed that it has the ability to comply with environmental regulations, but it has also spent years helping its suppliers improve their technology and operating procedures to conform to global requirements. Moreover, ensuring that suppliers achieve sustainability is equally important to balance the company's economic constraints. Hence, supplier management and maintaining stakeholder relations in the supply chain are very important to achieving sustainability (Zhu and Sarkis, 2004; Lu *et al.*, 2007; Vachon and Mao, 2008).

In addition, establishing flexible and clear technology in utilizing natural resources while complying with environmental regulations can help to develop a firm's resilience capability (Büyüközkan and Çifçi, 2013). Thus, the studied company is striving to develop a water recycling system and maintaining efforts to redesign its processes to reduce emissions, waste and energy consumption. Developing the ability to treat wastewater for reuse in production can enable the company to decrease the environmental burden of water extraction and endure environmental uncertainties or crises, such as the El Nino effect, which results in drought. When specific management interventions can ensure that flexible and clear technologies operate well, costs will decrease and stabilize (Montabon *et al.*, 2000; Carter and Rogers, 2008). Therefore, lifecycle assessments can be used to quantify the environmental performance of products, processes, or services and measure the firm's resilience (Fiksel, 2010).

In addition, responsiveness can enable the company to generate real-time feedback so it can understand its current SSCM position. While the adoption of sustainable practices is a daunting task (Zailani *et al.*, 2012), responsiveness is considered to be an important instrument to acquire information from the market and can be used to enhance customer service (Büyüközkan and Çifçi, 2013; Brindley and Oxborrow, 2014). The studied company sets a benchmark in responsiveness for maintaining positive relationships with stakeholders by disclosing the age of employees, their turnover rate, employee training statistics, the reasons for absences and their volunteer hours on the company website. This information provides a clear picture for investors and the public to understand how the studied company applies SSCM and shows that it is not merely a slogan within the company.

The proposed criteria offer a guideline for similar firms to develop their SSCM practices. Many studies have demonstrated that these criteria have a positive effect on SSCM performance (Beske, 2012; Wolf, 2014; Wu and Pagell, 2011). In accordance with these results, the studied company can improve its performance incrementally. The company can initially concentrate its resources on focal practices to enhance performance. Once the focal practices can be maintained using minimal resources, then the majority of the firm's resources can used to improve the last three criteria (usage of effective systems and tools, forecast accuracy, and enhancing customer service) that demonstrate insufficient SSCM performance.

7. Conclusions

The Taiwanese high-tech and electronics industry is striving to develop SSCM to conform to global regulations. Hence, this study proposed the use of collaboration theory to provide a theoretical basis for SSCM and adopted the concepts of congruence and alignment to enhance the understanding of integration of sustainability and SCM. However, SSCM practices require quantitative methods to assess performance due to often imprecise and uncertain information. To reduce evaluators' cognitive conflicts, linguistic variables are converted into IVTFNs to aid the evaluation process. Then, GRA can be used to overcome the uncertain situation and formulate the interactions into likelihood relations to rank the performance of SSCM practices.

The contributions of this study include not only enhancing the understanding of SSCM by filling gaps from previous studies but also proposing a hybrid measurement for the studied company to determine its SSCM performance. With regard to the theoretical implications, researchers should pay more attention to formulating the appropriate aspects and criteria through comprehensive literature reviews to ensure context validity and then modifying these aspects and criteria by consulting with experts to ensure the reliability of their empirical evaluations. In practice, top managers will then be able to measure current performance based on valid and reliable evaluations. Therefore, decision makers should apply this set of aspects and criteria to establish standards for continued improvement.

The empirical results support the argument that economic, environmental and social aspects are insufficient to cover the entire concept of SSCM. In particular, the aspects of operations, stakeholders and resilience have not been addressed in previous studies. Furthermore, the evaluation results provide a guideline for the studied company to implement SSCM. The company must consider supplier management in the initial stage and also enhance the alignment with the sustainability target. Once all of the supply chain members have coherent targets, the company can move on to practices such as developing flexible and clear technology, increasing responsiveness, ensuring compliance with environmental standards and increasing efficiency. These practices can also be considered a guideline for similar companies to implement SSCM.

This study formulated the SSCM aspects and criteria based on a single company. Future studies could modify those aspects and criteria to investigate different focal companies and then compare the results to establish a precise benchmarking of the practice and structure for a general SSCM framework that could be applicable to the entire high-tech and electronics industry. An extended study could also compare SSCM frameworks in different industries to determine the most common practices used to improve sustainable performance. Finally, SSCM is an advanced concept in current practice, and it therefore still lacks many precise aspects, criteria and empirical theories to comprehensively measure SSCM. To cross this boundary, the quality of information and the data gathering approaches may need to improve by using a combination of methods.

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