Social sustainable supply chain performance assessment using hybrid fuzzy-AHP–DEMATEL–VIKOR: a case study in manufacturing enterprises

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Abstract

Sustainable supply chain management (SSCM) has received extensive attention by academia and industries recently. However, there are increasing yet still scarce studies measuring the social sustainability performance of supply chain and discussing the interrelationship between social and economic sustainability. Further, the measurement does not fully utilize key performance indicators (KPIs) attributing to the lack of understanding of precise quantitative gauge of the supply chain social sustainable performance. To bridge this gap, this study analyses the social and economic sustainability performance in terms of demand planning, innovation, manufacturing, finance, sales and customer relationship, distribution and delivery and compliance. A framework is proposed to locate key metrics to evaluate the social sustainable supply chain (SSC) performance. A hybrid fuzzy-AHP–DEMATEL–VIKOR method is designed to investigate the social sustainability of supply chain. Data analysis and a case study are given to validate and support the feasibility and potency of the proposed approach. The robustness of our proposed model is executed via sensitivity analysis. From the proposed framework, demand planning and distribution and delivery are found to be the most critical criteria in economic and social dimension, respectively.

Keywords Social sustainability · Supply chain management · Fuzzy AHP · Fuzzy DEMATEL · Fuzzy VIKOR · Key performance indicators

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1 Introduction

Confronting the manufacturing industry explosive growths, the outlook of swift business development underlines the importance of a well-established supply chain (SC), which serves as the backbone of operational success (Khan et al., 2019). Yadlapalli et al. (2018) advocate that sustainable supply chain management (SSCM) development is a promising practice to remain companies' competitive advantages. Stakeholder pressures and governmental legislations further impel companies to attend to SSCM (Bai et al., 2019). The efforts toward SSCM are thus receiving ample interests. Hitherto, the economic and environmental aspects of SSCM have been studied extensively, yet social and economic sustainability research is at an embryonic stage (Mani et al., 2018b; Morais & Barbieri, 2022), which is conceptualized as reputable SC by Zhang (2011).

Research shows that social-oriented companies outperform other companies in both short and long terms (Longoni & Cagliano, 2015) and emphasizes supply chain social sustainability (SCSS) enables companies' image enhancement, competitive edge improvement and reduction of cost, labor disputes and supply chain risks (Cantele & Zardini, 2020; Mani & Gunasekaran, 2018). For example, Apple, Wal-Mart and Ford are conscious of these pressures and have strategically involved social sustainability into their supply chains (Klassen & Vereecke, 2012). Moreover, in response to COVID-19, many companies have been planning to strengthen their social sustainability (El Baz & Ruel, 2021; Gupta et al., 2020). Altogether SCSS concept includes products and process-related matters management that influence human safeties and social welfares of whom participating in upstream and downstream supply chains (Mani et al., 2016a). The extant literature has discussed the means to improve a company's SCSS in a scattered way (Awan et al., 2020; Carter & Easton, 2011; Gimenez et al., 2012). However, to incubate the ground for the business continuous development, it is crucial and obliged to address social sustainability not only at the intra-organization level, but also at the inter-organization level along the line of supply chain (Awan, 2019b; Rao, 2014). Consequently, an effective and efficient performance measurement system for a reputable SC is essential. Performance metrics and measurement methods or tools lay the foundation on establishing the system.

Among the SCSS studies, majorities address social sustainability of companies from the USA and Europe (Awan, 2019b; Ciliberti et al., 2008; Hervani et al., 2022), while the manufacturing companies from Asia are less explored with only a paucity of studies on companies from China (Lu et al., 2012; Ye et al., 2022) and India (Mani et al., 2016b; Mathivathanan et al., 2022). Klassen and Vereecke (2012) assert that social issues are temporal sensitive, contextual and dynamic, and generalization of social issues and outcomes is difficult on the grounds of diverse social norms. Thus, to bridge the gap, this study focuses on Singapore manufacturing companies. We select this particular target for two main reasons. First, the manufacturing sector contributes the largest portion of Singapore's economy. The industry is exposed in a multiracial, multicultural and multi-religious atmosphere. The ways the company handle products and operations of the supply chain that influence the safeties, health and welfares of people from different backgrounds, referring to SCSS, should be managed meticulously (Castka & Corbett, 2016). Second, the manufacturing sector desires continuous expansion. To this aim, it is essential to develop best business practices toward social sustainable supply chain (SSSC). By strengthening the sector's social reputation, the sector can attract more entrants and keep existing companies. Given this potential, we will focus on economic and social dimensions and explore the trade-off between these two aspects of SSCM, as there is need to investigate to what

extend the social sustainability affects the SC performance (Klassen & Vereecke, 2012; Mani et al., 2018a, 2018b). Additionally, we will address the holistic reputable SC performance involving all the entities—customers, suppliers and manufacturers simultaneously. With this context, the discussion from this study could provide comprehensive insights and advice to decision-makers to strive for a more social sustainable and profitable SC.

Specifically, the primary research objectives of this study are highlighted as follows:

(a) To identify the indicators reflecting economic and social performances as benchmark in manufacturing and service SCs.
(b) To develop a flexible framework to facilitate companies to evaluate their own reputable SC performance or the SC performance of their potential partners.
(c) To quantify the trade-off between the social and economic perspectives.
(d) To provide progressive perceptions about reputable SC performance in an environment alike Singapore.

To the best of our knowledge, this is the first study that integrates fuzzy analytic hierarchy process (AHP), fuzzy decision-making trial and evaluation laboratory (DEMATEL) and fuzzy Vlekriterijumsko KOmpromisno Rangiranje (VIKOR) to measure SSSC performance. The objectives are realized in two steps. First, by designing questionnaires and conducting interviews, a method is proposed seeking to find the key indicators used to evaluate the reputable SC performance. Second, a quantitative hybrid fuzzy AHP–DEMATEL–VIKOR method is provided to calculate the ratio of each indicator and build the evaluation system to rate companies' reputable SC performance.

The organization of this paper is structured as follows: Sect. 2 demonstrates previous literature regarding reputable SC performance management. Section 3 presents our framework and Sect. 4 discusses and analyses the results, followed by an empirical case study in Sect. 5. Section 6 provides discussions and limitations. Section 7 summarizes our findings and recommends future research directions.

2 Literature review

This section reviews and discusses previous research efforts focusing on the evaluation of reputable SC performance. The literature review is apportioned into three subsections. The first subsection reviews the key performance indicators. The second portion reviews the relative methodologies for the evaluation of reputable SC performance. Furthermore, an analysis of the previous studies is undergone to find the gap and explain the value of this work in the third part.

2.1 Reputable supply chain key performance indicators selection

Concurrently, the evaluation of reputable SC performance is a perennial problem for companies to improve sustainability and SC operational efficiencies. Although the interest in social sustainability is budding, its evaluation and corresponding indicator identification are still lacking (Fritz et al., 2017; Popovic et al., 2018). Ahi and Searcy (2015) summarize that there are 255 indicators identified from research till 2012, yet a majority of the indicators are only used once. Hence, an efficient technique for indicators categorization and selection plays a critical role (Ahi & Searcy, 2015).

There are several studies attempting to categorize and select indicators reflecting SCSS. Dale et al. (2013) identify 16 indicators and allocate them into three categories, namely social well-being, social acceptance and profitability. Besides, the social pillar in sustainable supply chain (SSC) from manufacturing companies in developing countries, such as India and Iran, are investigated by using the customer issues, health and safety and regulatory responsibility (Badri Ahmadi et al., 2017; Mani et al., 2016b). More specifically, studies have shown that the health and safety indicator is important to reflect the social sustainability of a company in options of both internal and external stakeholders (Büyüközkan & Karabulut, 2017; Li et al., 2019). However, the impact of health and safety on SSC performance has not been thoroughly studied (Yawar & Seuring, 2015). Further, the twin-dimensional factors of the product responsibility and health and safety reflecting social sustainability are remained to be explored in-depth. In this paper, we identify 50 social sustainability-related indicators under five categories on the grounds of literature review, as shown in Table 1.

2.2 Social sustainable supply chain management performance methodology

With the selected suitable performance metrics, multi-criteria decision-making (MCDM) methods (Khan et al., 2019) show the capability of effective measuring the reputable SC performance. Due to apparent advantages and robustness, the combination of these techniques, such as the fuzzy cognitive map (FCM) and the data envelopment analysis (DEA) or hybrid best–worst method (BWM) and TOPSIS framework, has gained usage for more sophisticated SSC performance evaluation (Abdel-Basset et al., 2020).

Among these plentiful methods used for SC performance modeling, AHP is generally the choice for considering expert judgements to rank decision options and is the most frequently used technique for prioritizing KPIs in SC performance measures (Ho & Ma, 2018; Lima-Junior & Carpinetti, 2017). Due to the practical limitation of AHP that only applies to low number of comparison problems (Ishizaka et al., 2012), combining AHP with other methodologies has been further studied. De Felice et al. (2015) use AHP in tandem with balanced scorecard (BSC) methodology to facilitate sustainable outsourcing evaluation in a SC. de Castro Vivas et al. (2019) employ an integrated model combining AHP and preference ranking organization method for enrichment evaluations (PROMETHEE) to investigate the SC sustainability. Shete et al. (2020) adopt AHP with Pythagorean fuzzy sets to identify and rank the sustainable SC innovation enablers of the Indian manufacturing industry to provide constructive advisories.

To cope with vagueness and information incompleteness, fuzzy-AHP has been implemented and integrated with other techniques in various SC performance measurement

Table 1 Social sustainability indicators extracted from previous literature

Researchers	Indicators
Veleva et al. (2001) and Kainuma and Tawara (2006)	Customer issues
Kuo et al. (2010)	Respect for the policy
Castka and Balzarova (2008) and Hartini et al. (2020)	Business practices
Azadnia et al. (2014), Luthra et al. (2017) and Hartini et al. (2020)	Occupational health and safety management system
Govindan et al. (2013) and Badri Ahmadi et al. (2017)	Contractual stakeholders influence

studies, especially in situations characterized by uncertainty and imprecision (Gandhi et al., 2016; Maestrini et al., 2017). Demirel et al. (2020) adopt fuzzy AHP–VIKOR technique to select suitable roll stabilizer type for motor yachts. Considering the existence of interdependencies among the criteria, with which AHP is incapable of dealing, integration of AHP, DEMATEL and fuzzy set theory can clarify the interrelationship among the criteria and reflect the properties of the system (Huang et al., 2007; Thakur et al., 2020). The combination has been employed in many areas, such as the green SC management (Rahman et al., 2019), urban freight transport (Kijewska et al., 2018), human resource and customer relationship management (Büyüközkan et al., 2017; Chou et al., 2019) and supplier selection (Kumar et al., 2018). Besides the integration of AHP and other MCDM techniques, there are other combinations for performance measure. Azadmanesh and Maleki (2022) apply the integration of BWM and fuzzy inference system to evaluate companies' sustainable performance. Erol et al. (2022) adopt fuzzy SWARA-COPRAS-EDAS and COPELAND-based framework to examine the feasibility of blockchain in sustainable supply chain. In response to COVID-19, there is research using integration of ANP and TOPSIS to investigate SC sustainability and resilience (Magableh & Mistarihi, 2022). Similarly, Hervani et al. (2022) use the supply chain operations reference (SCOR) model to evaluate the social S sustainability and resilience. However, these adopted combinations lack the ability to assess and evaluate the targeted system in a holistic manner.

2.3 Research gaps

According to the previous literature, we identified four research gaps to open avenues for this research.

- The current research discussed mainly focuses on the performance indicators selection and methodology of SC management; however, as stated by Morais and Barbieri (2022), a paucity of studies involve a standard framework to identify the indicators and evaluate the social sustainability performance, especially in the context of Asia culture.
- The evaluation generally focuses on one entity in the SC without considering the influence from other entities.
- The investigation of functions including demand planning, innovation, manufacturing and sales and customer relationships is limited. The indicators mentioned in the previous literature have yet been explored well on social and economic perspectives.
- AHP is incapable of dealing with the existence of interdependencies among the criteria.

As such, the novelty of this research resides on addressing the gap by developing a framework to evaluate the SSC performance from economic and social perspectives covering all the traditional SC functions, including demand planning and innovation, etc. To the best knowledge of the authors, Singapore manufacturing companies have not been studied in this field. Hence, this research expand the frontier in this area by studying Singapore manufacture sector. The trade-off will be quantified and visualized to the stakeholders for better impetus of SC operation. Due to the above-mentioned insufficiencies of hybrid fuzzy AHP and other MCDM tools, and considering limited approaches to measure reputable SC performance quantitatively, a fuzzy AHP–DEMATEL–VIKOR method is proposed to process the natural language based on stakeholders and experts' opinions and to verify the interrelationship among criteria and thus evaluate the holistic SSSC system with ranking provided.

3 Research and data methodology

3.1 Criteria selection and panel interviews

3.1.1 Social and economic indicators selection

Reputable SC performance measurement should be capable of providing the practitioners the insights that to what extent their SCs are economic and social sustainable. There are tremendous indicators to evaluate reputable SC performance. The metrics used should truly reflect the organization situation. The selected metrics in our study aim at achieving a balance between economic and social measures. Eighty-nine criteria are chosen from literature review and experts' options, aiming at demonstration of the performance efficiencies from strategic, tactical and operational perspectives. Furthermore, to better understand social responsibility awareness of the holistic SC, the selected criteria involve indicators measuring economic and social performance of suppliers and customers.

A typical SC involves several functional areas to maintain social and economic sustainability. We choose several criteria in terms of the economic and social dimensions under the key functional areas shown in Fig. 1.

- *Economic dimension*

  Demand planning metrics serve two purposes—profit improvement opportunities identification and accountability driven. An accurate forecast model cultivates an effective and smooth demand-planning sector and thus smooths SC operations. Consequently, the indicators reflecting the forecasting model performance are considered as representatives. Furthermore, measurements of financial indicators are used to deter-

Fig. 1 Key function areas in supply chain management

mine the economic sustainability of a company in its management of revenue, cost, cash flow and investment. Innovation in this study includes product innovation, process innovation, organizational innovation, marketing and technological innovation, which is prominent to continuous business development in the increasingly competitive global market and fully reflects the economic sustainability level. The performance indicators of these five types of innovation are to be examined.

- *Social dimension*

    To measure the social sustainability, 4 criteria are considered. Manufacturing is one of the core functions, the corresponding indicators are designed to be aligned to a company's goals and objectives, which are improving quality and efficiency and productivity to maintain customer satisfaction and loyalty and reduce the risks. Sales and customer relationship management are geared toward different sales targets, videlicet to retain customers, expand in existing markets and penetrate new geographical areas and industries. Additionally, as customers play a critical role in a SC, the interaction with customers is a key characteristic to improve SC social sustainability. Hence, it is necessary to investigate the responsiveness to customers' feedback. The metrics of compliance in our study include health and safety incidents and product safety to evaluate the employee working condition.

Table 2 demonstrates context-specific terms representing the explored above-mentioned dimensions. However, the causal relationships among such large amounts of indicators exist and may disperse managers' attention and make the focal point indistinct. To simplify and construct a superior evaluation system, the internal relationship is identified and the size of the criteria pool is condensed further.

3.1.2 Data collection method

The semi-structured interview is the most extensively exploited interview format for empirical data collection, with the advantage of discovering unexplored and novel information (O'Keeffe et al., 2016). In comparison with structured and unstructured interviews, the semi-structured interview is more applicable to delve into the interviewees' background and perceptions regarding complicate issues. To portray a comprehensive picture of the SSC from the interviews, a thorough literature review on economic and social indicators identification, categorization and assessment is conducted initially. Sequentially, a questionnaire is designed and interviews are performed with identified respondents to collect the needed data.

3.2 Performance measurement framework

As discussed in Sect. 2, the previous used methodologies incapacitate evaluation of the SSSC performance in a full picture. For example, Hervani et al. (2022) use environmental goods valuation methods to evaluate the social sustainability, however, without experts' opinions and without providing rank for companies. Under such context, the empirical data collected through semi-structured interviews are processed using an integrated framework of three techniques—fuzzy AHP, fuzzy DAMETAL and fuzzy VIKOR. These three methods facilitate to unearth various possible implications from a single data source (Clarke et al., 2015) and complement the disadvantages and take the advantages of each individual method (Frost et al., 2011). Fuzzy set can digest the

Table 2 KPIs for reputable supply chain performance assessment

Category	KPIs/criteria	No.	Sub-criteria
Economic	Demand planning C_1	1	Forecast accuracy
		2	Forecast error
		3	Forecast attainment
		4	Forecast model bias
		5	Period over period error trend
		6	Rolling out-of-sample errors
		7	Finished goods inventory turns
		8	Inventory absence as a percentage of total inventory
		9	Demand/supply cost per $1000 in revenue
	Finance C_2	1	Earnings per share
		2	Reliance on revenue source
		3	EBITDA
		4	Net profit margin
		5	Gross profit margin
		6	Revenue
		7	SGA to sales
		8	Operating expense ratio
		9	Inventory turnover
		10	Operating self sufficiency
		11	Current ratio
		12	Quick ratio
		13	Cash asset ratio
		14	Interest coverage ratio
		15	Cash-to-cash cycle
		16	Account receivables turnover
		17	Account payables turnover
		18	Return on equity
		19	Return on investment
		20	Return on assets
		21	Total asset turnover
		22	Working capital
Economics	Innovation C_3	1	Revenue from new offerings
		2	Incremental sales-driven by new innovation
		3	Projected versus actual performance
		4	Number of projects meet planned targets
		5	Total investment in growth project
		6	Average development time per project
		7	Speed to market
		8	Number of intellectual property
		8	Freight bill accuracy
		9	Freight cost per unit
		10	Fill rate
		11	Average delivery time
		12	Percent of truckload/ container capacity utilized

Table 2 (continued)

Category	KPIs/criteria	No.	Sub-criteria
		13	Vehicle turnover time
		14	Average number of stop per route
		15	Fleet yield
Social	Sales and customer relationship C_4	1	Number of converted leads
		2	Number of successful tenders
		3	Market share
		4	Accuracy of sales quotations
		5	Timeliness of sales quotations
		6	On-time delivery
		7	Volume of resolved issues
		8	Volume of active issues
		9	Complaint escalation rate
		10	Customer return rate
		11	Average resolution time
		12	Customer Retention Rate
		13	Net Promoter Score
		14	Customer Effort Score
		15	Customer Satisfaction Score (CSAT)
	Manufacturing C_5	1	Manufacturing yield
		2	Customer rejection rate
		3	Number of critical quality issues
		4	Supplier incoming quality
		5	Overall equipment effectiveness
		6	Manufacturing cost
		7	Productivity per employee
		8	WIP inventory/turns
		9	Capacity utilization
	Manufacturing C_5	10	Throughput
		11	Schedule or production attainment/planned
		12	Downtime in proportion to operating time
		13	Energy cost per unit
		14	Order fill rate
		15	Cycle time
		16	Time to make change over
	Compliance C_7	1	Environmental incidents per year
		2	Safety and health incidents per year
		3	Product safety incidents per year
		4	Export control incidents per year

vagueness and information incompleteness. AHP enables effective coordination of various factors. However, due to incapability of AHP to capture the interdependencies among factors, DEMATEL is used to scrutinize the interrelations among factors. It is noteworthy that adopting DEMATEL only is possible to face dilemma as the technique

cannot evaluate more critical factors (Huang et al., 2022). Then the fuzzy VIKOR technique uses the weights calculated by fuzzy-DEMATEL to rank the candidates.

The framework contains four major phases as shown in Fig. 2. Phase 1 is to determine the criteria used and conduct panel interviews to decide the comparative weight of each criterion. During panel interviews, with the structural performance assessment system, decision-makers opt for the importance of each criterion by making pairwise comparisons using a preference scale of 1 to 5. Phase 2 is to construct the fuzzy AHP matrix and compute the fuzzy weight of each criterion. The weight is then defuzzified and normalized. Phase 3 is to determine the indicators from each criterion group and computing the corresponding weights using fuzzy DEMANTEL. The last phase is to determine the rank of alternative companies based on the calculated value of S, R and Q using the selected indicators via fuzzy VIKOR method. The subsections below elaborate each phase of the proposed framework in details.

3.2.1 Fuzzy AHP method

The AHP (Analytic Hierarchy Process) method developed by Saaty (1980) is widely used to prioritize various decision criteria to facilitate better options. It performs pairwise comparison between alternatives to establish relations within the structure (Saaty, 1980). To eliminate the impact of diverse human subjectivities and consciousness, fuzzy AHP is developed as a
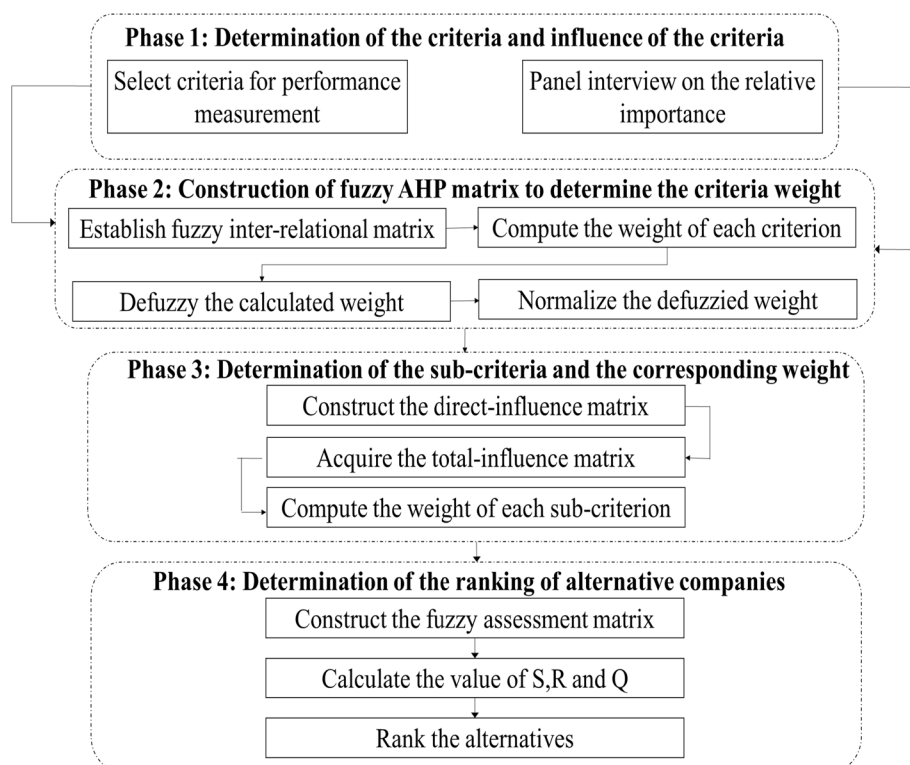

Fig. 2 The framework of the proposed methodology to evaluate performance

synthesis of fuzzy set theory and hierarchical structure evaluation aiming at resolving selection and decision-making problems, enabling digestion of impreciseness and uncertainties (Güngör et al., 2009), and builds a robust strategic guideline to assist the stakeholders to make decisions (Chan & Kumar, 2007).

The pairwise comparison of fuzzy AHP in the perception matrix extracted from experts' interviews is a fuzzy number, and a fuzzy algorithm and aggregation operator are adopted to obtain a sequence of weight vectors for the main attributes selection. In some cases, a decision-maker may specify a preference in the form of a pairwise comparison of AHP values with the representation of nine importance scales. If the decision-maker has difficulty to enumerate his/her preferences, he/she can elaborate preferences regarding the importance of each performance attribute in the form of a natural language expression. Besides, the decision-makers can also use fuzzy linguistic terms to construct a lookup table of values and derive its corresponding values to the fuzzy number. The outlines of fuzzy AHP application are depicted as follows.

Step 3.1.1: The initial step is to establish a hierarchical assessment questionnaire. The judgement from decision-makers is translated into fuzzy triangle numbers.

Step 3.1.2: Under circumstances that the decision-makers have difficulties expressing their judgement using fuzzy triangles, they can provide preferences through linguistic variables and easily derive the equivalent fuzzy triangular values from the lookup table as shown in Fig. 3.

Step 3.1.3: Upon establishing the hierarchy and pairwise comparison of the alternative criteria, the global priority weight of the alternative is calculated.

3.2.2 Weight determination of the selected criteria

Step 3.2.1: Upon criteria selection, the importance of criteria is compared using linguistic terms shown in Table 3 (Jayawickrama et al., 2017). A comparison matrix can be obtained with the scales as shown:

$$M = \begin{bmatrix} m_{11} & \cdots & m_{1j} \\ \vdots & \ddots & \vdots \\ m_{i1} & \cdots & m_{ij} \end{bmatrix}$$

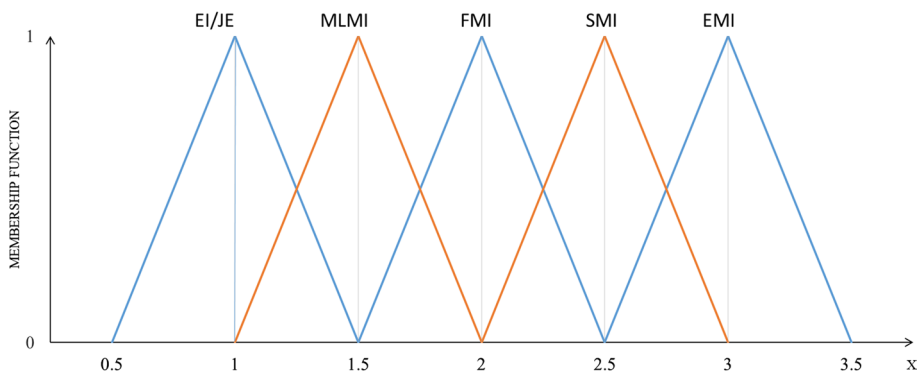where m_{ij} indicates the fuzzy scale resulted from comparison of ith criterion with jth criterion.

Fig. 3 Membership functions for rating criterion weights

Table 3 Linguistic scale for pairwise comparison

Linguistic scales	Fuzzy numbers	Reciprocal fuzzy numbers
Just equal (JE)	(1, 1, 1)	(1, 1, 1)
Equal importance (EI)	(1/2, 1, 3/2)	(2/3, 1, 2)
More or less more importance (MLMI)	(1, 3/2, 2)	(1/2, 2/3, 1)
Fairly more importance (FMI)	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Strongly more importance (SMI)	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Extremely more importance (EMI)	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

Step 3.2.2: The value of geometric mean for the ith criterion $\widetilde{r}_i$ is calculated by Eq. (1) (Burney & Ali, 2019).

$$\widetilde{r}_i = \left(\prod_{j=1}^{n} m_{ij} \right)^{1/n}, \quad i = 1, 2 \dots, n \tag{1}$$

Step 3.2.3: The weight of each criterion is computed using Eq. (2).

$$\widetilde{w}_i = \widetilde{r}_i \times \left(\sum_{i=1}^{n} \widetilde{r}_i \right)^{-1}, \quad i = 1, 2, \dots, n \tag{2}$$

with $\left(\sum_{i=1}^{n} \widetilde{r}_i \right)^{-1}$ in the increasing order.

Since $m_{ij} = \left(m_{lij}, m_{mij}, m_{uij} \right)$, w_i can be expressed as shown in Eq. (3):

$$\begin{cases} w_{lij} = r_{li} \times \left(\sum_{i=1}^{n} r_{li} \right)^{-1} \\ w_{mij} = r_{mi} \times \left(\sum_{i=1}^{n} r_{mi} \right)^{-1}, \quad i = 1, 2, \dots, n \\ w_{uij} = r_{ui} \times \left(\sum_{i=1}^{n} r_{ui} \right)^{-1} \end{cases} \tag{3}$$

Step 3.2.4: The calculated weight is defuzzified using center of area (COA) defuzzification method as shown in Eq. (4) (Khan et al., 2018):

$$w_i = \frac{(w_{uij} - w_{lij}) + (w_{mij} - w_{lij})}{3} + w_{lij} = \frac{w_{lij} + w_{mij} + w_{uij}}{3} \tag{4}$$

Step 3.2.5: The defuzzified weight need to be normalized using Eq. (5):

$$w_{in} = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{5}$$

3.2.3 Fuzzy DEMATEL method

The DEMATEL, developed by the Battelle Memorial Institute, is used to resolve complicate and comprehensive decision-making problems and determine the internal relationship among each sub-criterion and measure qualitative and factor-linked aspects of societal problems (Gabus & Fontela, 1972). It is widely deemed as one of the most reliable tools to perceive

the interdependence relationship among evaluated indicators (Lin & Tzeng, 2009). The tool divides the indicators into cause and effect groups, respectively, and shows the quantitative influencing effects. The interdependence among the indicators, thus, can be revealed. Simultaneously the less influencing factors are eliminated to improve the measure effectiveness. Consequently, key indicators for performance evaluation are selected. Organizations can strengthen specific factors efficacy based on the causal results. In this research, the fuzzy set theory is integrated into the DEMATEL technique to absorb the uncertainty and vagueness of human subjectivities. The technique details are described as follows.

Step 3.3.1: To design the fuzzy linguistic scale and generate a fuzzy initial direct-influence matrix $\widetilde{T}$ for pairwise comparison.

Designated experts are invited to provide their judgements on the relative importance among each pair of the indicators. The jth indicators are denoted as C_j with $j = 1, 2, \ldots, n$. There are n indicators and m experts with E_i denoting the rth expert ($r = 1, 2, \ldots, m$). Table 4 lists levels of linguistic variables and the corresponding triangular fuzzy numbers. t_{rij} represents the initial direct-influence element that the influence C_i has on C_j assessed by the rth expert. Subsequently, the collective judgment of m experts is calculated by generating the average matrix $\widetilde{T}$ with each element $\widetilde{T_{ij}} = \frac{t_{1ij} \oplus t_{2ij} \oplus \cdots \oplus t_{rij}}{r}$.

Step 3.3.2: To generate the normalized direct-influence matrix $\widetilde{A}$ by normalizing the aggregated fuzzy decision matrix $\widetilde{G}$. As $\widetilde{G_{ij}} = (g_{ij}^l, g_{ij}^m, g_{ij}^u)$, where $g_{ij}^l, g_{ij}^m, g_{ij}^u$ represent the fuzzy lower bound, middle value and upper bound in the initial direct-influence matrix, respectively. The normalized direct-influence information is calculated using Eq. (6):

$$\widetilde{A}_{ij} = \frac{\widetilde{G_{ij}}}{a} = \left(\frac{g_{ij}^l}{a}, \frac{g_{ij}^m}{a}, \frac{g_{ij}^u}{a} \right) = (a_{ij}^l, a_{ij}^m, a_{ij}^u) \tag{6}$$

where $a_{ij}^l, a_{ij}^m, a_{ij}^u$ denote the fuzzy lower bound, middle value and upper bound of $\widetilde{A}$, respectively. All elements $\widetilde{A}_{ij}$ in $\widetilde{A}$ are in line with $0 \leq \widetilde{A}_{ij} \leq 1$. The normalizing factor a is calculated as follows

Table 4 The linguistic scales employed for fuzzy DEMATEL assessment (Tadić et al., 2014)	Linguistic terms	Corresponding triangular fuzzy numbers
	None	(0.1, 0.1, 1)
	Very low	(0.1, 1, 2)
	Low	(1, 2, 3)
	Fairly low	(2, 3, 4)
	More or less low	(3, 4, 5)
	Medium	(4, 5, 6)
	More or less high	(5, 6, 7)
	Fairly high	(6, 7, 8)
	High	(7, 8, 9)
	Very high	(8, 9, 10)
	Extremely high	(9, 10, 10)

$$a = \max\left(\max_{1 \leq i \leq n} \sum_{j=1}^{n} g_{ij}, \max_{1 \leq j \leq n} \sum_{i=1}^{n} g_{ij} \right)$$

Step 3.3.3: To acquire the total-influence matrix $\widetilde{V}$ by Eq. (7)

$$\widetilde{V} = \lim_{r \to \infty}(\widetilde{N} \oplus \widetilde{N}^2 \oplus \cdots \oplus \widetilde{N}^r) = \widetilde{N} \times (I - \widetilde{N})^{-1} \text{ when } r \to \infty, \ \widetilde{N}^r = [0]_{n \times n} \quad (7)$$

$\widetilde{V}_{ij} = (v_{ij}^l, v_{ij}^m, v_{ij}^u)$ and $v_{ij}^l, v_{ij}^m, v_{ij}^u$ denote the fuzzy representation of the total-influence matrix, respectively. And $v_{ij}^l = n_{ij}^l \times (1 - n_{ij}^l)^{-1}, v_{ij}^m = n_{ij}^m \times (1 - n_{ij}^m)^{-1}$ and $v_{ij}^u = n_{ij}^u \times (1 - n_{ij}^u)^{-1}$. I represents the identity matrix.

Step 3.3.4: To acquire the defuzzified total-influence matrix V by Eq. (8)

$$v_{ij} = v_{ij}^l + 4v_{ij}^m + v_{ij}^u \Big/ 6 \quad (8)$$

where v_{ij} denotes the crisp total-influence of the jth criterion in comparison with the ith criterion.

Step 3.3.5: To obtain the summation of rows and columns of V, denoting as vector D and R, as shown in Eq. (9), respectively.

$$\begin{cases} D = (D_i)_{n \times 1} = \left[\sum_{j=1}^{n} v_{ij} \right]_{n \times 1} \\ R = (R_j)_{n \times 1} = \left[\sum_{i=1}^{n} v_{ij} \right]_{1 \times n} \end{cases} \quad (9)$$

D_i and R_j denote the summation of rows and columns of the total-influence matrix of the ith criterion, respectively. Then the addition and subtraction of the two vectors are calculated. $D_i + R_j$ reveals the impact of the ith criterion on the entire system and simultaneously the impact of jth criterion on ith criterion. On the contrary, $D_i - R_j$ presents the net effect of the ith criterion on the system. A positive value of $D_i - R_j$ represents that the ith criterion falls into the net cause group and affects other criteria. On the contrary, a negative value of $D_i - R_j$ reveals that the criterion will be categorized into the net effect group (Lee et al., 2009; Ou Yang et al., 2008).

Step 3.3.6: Corresponding weights of each indicator are obtained by Eqs. (10) and (11) (Zhang & Chen, 2017):

$$w_i^* = \sqrt{(D_i + R_j)^2 + (D_i - R_j)^2} \quad (10)$$

$$w_i = \frac{w_i^*}{\sum_{i=1}^{n} w_i^*} \quad (11)$$

3.2.4 Fuzzy VIKOR technique

The VIKOR technique is an effective MCDM method to solve discrete complex decision problems with conflicting criteria (Opricovic & Tzeng, 2007). It is instrumental for decision-makers to figure out a compromise optimal solution. The final ranking result of the alternatives is provided considering each criterion. To deal with information ambiguity

and uncertainty, fuzzy set theory is integrated into the technique, allowing decision-makers to rate the alternatives with linguistic variables. The calculation of fuzzy VIKOR ranking index is recounted as follows.

Step 3.4.1: To construct the assessment matrix

The alternatives to be selected and indicators are initially identified. The fuzzy decision matrix is built based on assessment values of each alternative as shown in Table 5 with respect to the indicators used and expressed as follows:

$$\widetilde{\boldsymbol{D}} = \begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{12} & \cdots & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \cdots & \widetilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \widetilde{x}_{m1} & \widetilde{x}_{m2} & \cdots & \widetilde{x}_{mn} \end{bmatrix}$$

where $\widetilde{x}_{ij}(i = 1, 2, \ldots, m, j = 1, 2, \ldots, n)$ refers to the performance score of alternative A_i with respect to indicator C_j. $\widetilde{x}_{ij} = \left(x_{ij}^1, x_{ij}^2, x_{ij}^3, x_{ij}^4\right)$ where $x_{ij}^1, x_{ij}^2, x_{ij}^3, x_{ij}^4$ denote the fuzzy performance rating, respectively.

Step 3.4.2: To defuzzify the fuzzy decision matrix by using COA defuzzification relation shown as Eq. (12).

$$x_{ij} = \frac{x_{ij}^{(1)} + x_{ij}^{(2)} + x_{ij}^{(3)} + x_{ij}^{(4)}}{4} \tag{12}$$

Step 3.4.3: To determine the fuzzy best value f_j^* and the fuzzy worst value f_j^- for each criterion.

$$f_j^* = \max x_{ij} \tag{13}$$

$$f_j^- = \min x_{ij} \tag{14}$$

where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

Step 3.4.4: To calculate the normalized difference value S_i and R_i using Eq. (15).

$$\begin{cases} S_i = \sum_{i=1}^n \frac{w_j(f_j^* - x_{ij})}{f_j^* - f_j^-} \\ R_i = \max \frac{w_j(f_j^* - x_{ij})}{f_j^* - f_j^-} \end{cases}, \quad i = 1, 2, \ldots, m \tag{15}$$

Table 5 Linguistic terms and fuzzy numbers transformation system (Saket et al., 2015)	Linguistic variable	Abbreviation	Triangular fuzzy number
	Very high	VH	(0.8, 0.9, 1.0, 1.0)
	High	H	(0.7, 0.8, 0.8, 0.9)
	Above average	AA	(0.5, 0.6, 0.7, 0.8)
	Average	A	(0.4, 0.5, 0.5, 0.6)
	Below average	BA	(0.2, 0.3, 0.4, 0.5)
	Low	L	(0.1, 0.2, 0.2, 0.3)
	Very low	VL	(0.0, 0.0, 0.1, 0.2)

Step 3.4.5: To compute the value Q_i using Eq. (16) revealing the total deviation of the alternatives from the ideal solution (Tadić et al., 2014).

$$Q_i = v\frac{S_i - \min_i S_i}{\max_i S_i - \min_i S_i} + (1 - v)\frac{R_i - \min_i R_i}{\max_i R_i - \min_i R_i} \tag{16}$$

where v is a decision mechanism which refers to a weight for the strategy of the maximum group utility, while $1 - v$ refers to the weight of the individual regret (Liu, 2016).

Step 3.4.6: To arrange the value of S, R and Q in ascendant sequence and rank the alternatives.

Step 3.4.7: The alternative with the minimum Q value is considered the best option if two conditions mentioned below are satisfied, otherwise a compromise solution is proposed:

Condition 1. Acceptable advantage:

$$Q(A_1) - Q(A_2) \leq 1/(m - 1), \tag{17}$$

where A_2 is the alternative with second rank measured by Q value.

Condition 2. Acceptable stability in decision-making: the best ranked alternative A_1 is requested simultaneously possess the minimum value of S or/and R, then the obtained solution is considered stable.

A group of alternative compromise solutions is offered when either condition is not fulfilled. **Compromise solution 1.** If the first condition is not met, alternatives $A_1, A_2, \ldots, A_C$ are the solutions with A_C determined by the function of $Q(A_2) - Q(A_1) < 1/(m - 1)$ for maximum C (the position of these alternatives in closeness).

Compromise solution 2. Alternatives A_1 and A_2 are the solutions under the condition that the second condition is not satisfied.

## 4 Data analysis and findings

4.1 Case study

This study first collects empirical evidence with semi-structured interviews from 16 selected experts with the assistance of Supply Chain Asia. They have diverse backgrounds from different manufacturing and service companies and different levels of experience in Singapore. The questionnaire is designed to receive general information about the experts' background. Sequentially the specific information about the operation and relation with suppliers and customers is collected. For each category, open-ended questions are asked to understand about their opinions on the indicators influencing the performance. They can answer freely regarding the content. In total 10 completed surveys are collected. To examine the tangibility of the proposed framework, this section conducts an experiment to evaluate companies' social and economic sustainability performance of their SCs and identify the degree of trade-off between social and economic aspects.

With key indicators selection, two manufacturing companies X and Y from Singapore are investigated to validate the proposed framework. Due to confidential concerns, the companies' information is kept anonymous. Both companies produce two types of products. Under different background, it is difficult to suggest which company performs better intuitively. To escape the dilemma, the reputable SC performance is evaluated

Table 6 The weight and normalized weight of each criterion

Criterion	$\widetilde{w_i}$			Defuzzified weight w_i	Normalized weight w_{ni}
Demand planning (C_1)	0.151	0.236	0.352	0.2465	0.2294
Finance (C_2)	0.073	0.108	0.165	0.1154	0.1074
Innovation (C_3)	0.093	0.147	0.228	0.1559	0.1451
Sales and customer relationship (C_4)	0.086	0.143	0.228	0.1524	0.1418
Manufacturing (C_5)	0.07	0.107	0.171	0.116	0.1079
Distribution and delivery (C_6)	0.093	0.15	0.266	0.1696	0.1578
Compliance (C_7)	0.06	0.107	0.189	0.1187	0.1104
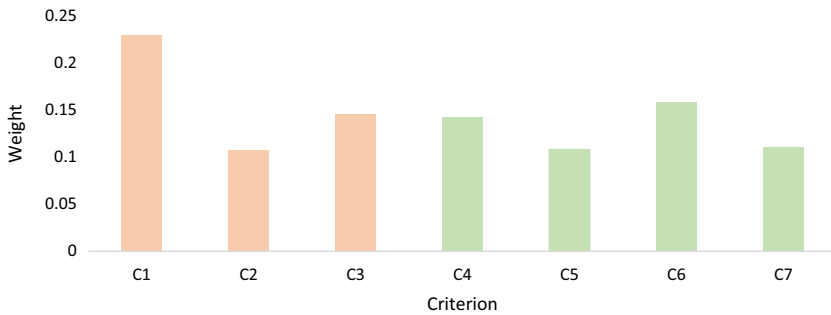
Fig. 4 Weight ratios of each criterion

by using the fuzzy VIKOR technique. And the KPI tree for the reputable SC performance evaluation is established to rank targeted companies' performance by quantified indicators. The final score obtained can be a guideline to compare the reputable SC performance of companies. In the end, the sensitivity analysis is conducted to check the robustness of the proposed framework.

The influential weights of the seven criteria (categories) $(C_1, C_2, \ldots, C_7)$ are calculated using the fuzzy AHP as shown in Table 6. Figure 4 illustrates the weight ratio distribution of each criterion with orange color representing economic pillar and green representing social pillar. The demand planning is found to be the most important criterion in the performance evaluation matrix, followed by distribution and delivery under social dimension. This phenomenon reflects raising prominence of the social responsibility of a company and implies the industry starts a drive to a more SSSC, namely reputable SC. The third most weight-carrying category is innovation. Innovation has been found profoundly impacting on supply chain operations and decision-making, and facilitating more effective collaboration and coordination among SC-involved parties (Sabri et al., 2018). Innovation also ensures the business continuity and hence strengthens the economic sustainability and has strong positive influence on improving social sustainability. In brief, it can be seen that social sustainability plays an equal critical role as economic sustainability.

Subsequently, the sub-criteria of each criterion is probed into separately using the fuzzy DEMATEL technique. The normalized fuzzy direct-relation matrix for each criteria category is constructed using Eq. (6).

Fuzzy total-relation matrices are calculated using Eq. (7) and defuzzified with Eq. (8). The defuzzified total-relation matrices quantify the interdependent relationship between the sub-criteria within one criterion group. The inner dependencies matrices for the other five criteria group are calculated with the same method. The D and R are also calculated to sum up the row and column of the defuzzified total-relation matrix, respectively.

Then the values of $D + R$ and $D - R$ are obtained. $D + R$ refers to the importance degree of the sub-criterion, and $D - R$ perceives the influencing extent. Table 7 provides the example of the defuzzified total-relation matrix and the value of $D + R$ and $D - R$ for sub-criteria of the demand planning group. The positive value of $D - R$ directs the corresponding factor into the cause group, conversely, the corresponding factor with a negative value to the effect group. In our study, the sub-criteria in the cause group is selected to be employed to investigate the SSSC performance by applying the fuzzy VIKOR technique.

The selected indicators of each category form a KPI tree as shown in Fig. 5. Table 8 displays the global weight of each indicator. Consequently, 39 indicators are selected. It can be observed that the relative most important indicator is C_{73} (the number of product safety incidents per year), followed by C_{11} (forecasting accuracy). Moreover, the total weight of the social dimension is 51.8% implying slightly more attention shifted to social sustainability. The KPI tree can be used to evaluate the reputable SC performance of companies and obtain the rank. Using the rank as a guideline, decision-makers can find appropriate potential business partners.

Table 9 shows the ratings of the two alternative companies. The fuzzy decision matrix is then built based on the relation shown in Table 6, and the fuzzy numbers are defuzzified into crisp numbers by applying Eq. (12), as shown in Table 10. The best f_j^* and f_j^- of the alternatives for the 39 selected indicators are calculated, followed by computation of the values of S_i, R_j and Q_i. The value of v is generally set to be 0.5 by consensus rule. $\min_i S_i = 0.272$, $\max_i S_i = 0.728$, $\min_i R_i = 0.061$ and $\max_i R_i = 0.063$ are computed. Table 12 presents the ranks of the two alternative companies' reputable SC performance with the S_i, R_j and Q_i values sequencing in the ascending order. It shows that the alternative A_1 outperforms A_2 based on the value of Q_i (smaller, the better). The two conditions in Sect. 3.2.4 must be checked for validation.

(1) Condition 1. Acceptable advantage

Table 7 Defuzzified total-relation matrix for indicator of demand planning category

|	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	D	R	$D+R$	$D-R$
C_{11}	0.161	0.335	0.339	0.338	0.339	0.405	0.334	0.419	0.428	3.097	1.411	4.508	1.686
C_{12}	0.169	0.158	0.327	0.324	0.327	0.392	0.319	0.408	0.419	2.842	1.593	4.435	1.249
C_{13}	0.149	0.145	0.109	0.126	0.109	0.302	0.128	0.318	0.332	1.718	1.897	3.615	−0.179
C_{14}	0.167	0.159	0.299	0.133	0.299	0.362	0.150	0.38	0.395	2.342	1.781	4.123	0.561
C_{15}	0.149	0.145	0.109	0.126	0.109	0.302	0.128	0.318	0.332	1.718	1.897	3.615	−0.179
C_{16}	0.157	0.157	0.129	0.13	0.129	0.139	0.144	0.318	0.333	1.634	2.594	4.227	−0.96
C_{17}	0.160	0.164	0.311	0.308	0.311	0.376	0.14	0.393	0.406	2.569	1.654	4.223	0.915
C_{18}	0.162	0.166	0.132	0.146	0.132	0.159	0.156	0.152	0.33	1.535	2.872	4.407	−1.337
C_{19}	0.135	0.165	0.142	0.151	0.142	0.158	0.158	0.167	0.159	1.376	3.132	4.508	−1.756
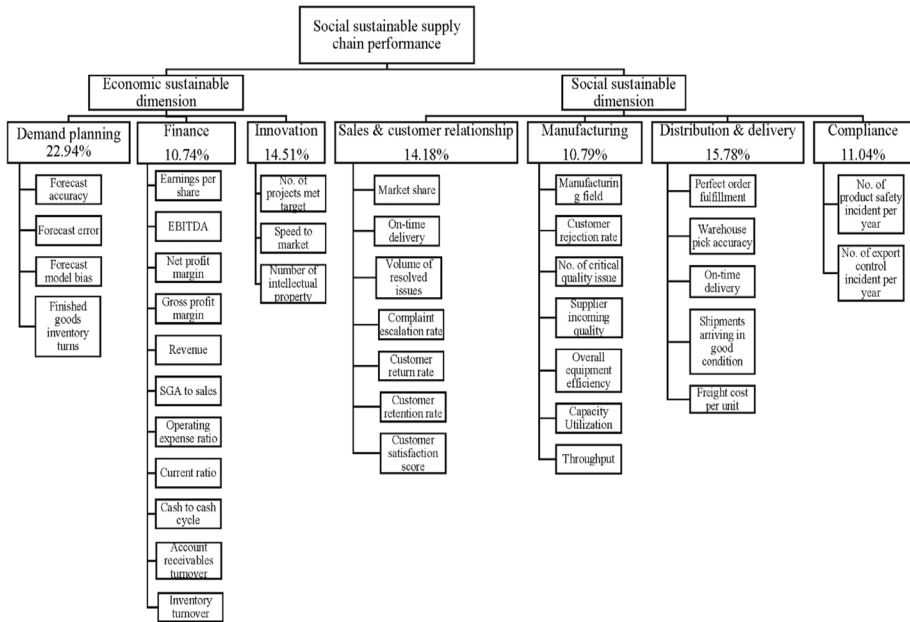
Fig. 5 KPI trees for the SSC performance measurement

Table 8 Global normalized weight of each indicator

	C_{11}	C_{12}	C_{14}	C_{17}	C_{21}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{211}
Weight	0.062	0.059	0.053	0.055	0.009	0.008	0.009	0.009	0.008	0.01	0.01	0.011	0.012
	C_{215}	C_{216}	C_{34}	C_{37}	C_{38}	C_{43}	C_{46}	C_{47}	C_{49}	C_{410}	C_{412}	C_{415}	C_{51}
Weight	0.012	0.01	0.046	0.047	0.052	0.018	0.02	0.021	0.022	0.021	0.021	0.019	0.014
	C_{52}	C_{53}	C_{54}	C_{55}	C_{59}	C_{510}	C_{61}	C_{63}	C_{65}	C_{67}	C_{69}	C_{73}	C_{74}
Weight	0.015	0.013	0.015	0.016	0.017	0.017	0.034	0.03	0.035	0.03	0.029	0.063	0.047

Table 9 Linguistic assessment from decision-makers for the two alternatives

	C_{11}	C_{12}	C_{14}	C_{17}	C_{21}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{211}
A1	H	L	L	VL	H	BA	AA	AA	VH	VH	VH	AA	BA
A2	VH	VL	VL	VH	L	H	H	H	H	H	H	A	H
	C_{215}	C_{216}	C_{34}	C_{37}	C_{38}	C_{43}	C_{46}	C_{47}	C_{49}	C_{410}	C_{412}	C_{415}	C_{51}
A1	VH	VH	AA	VH	AA	VH	H	VH	A	A	VH	VH	VH
A2	H	H	A	BA	A	H	BA	AA	AA	AA	H	H	H
	C_{52}	C_{53}	C_{54}	C_{55}	C_{59}	C_{510}	C_{61}	C_{63}	C_{65}	C_{67}	C_{69}	C_{73}	C_{74}
A1	L	L	BA	BA	H	H	H	H	H	H	H	H	VH
A2	VL	BA	L	A	VH	AA	AA	BA	AA	AA	VH	AA	H

Table 10 Crisp decision matrix for the two alternatives

	C_{11}	C_{12}	C_{14}	C_{17}	C_{21}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{211}
A_1	0.8	0.2	0.2	0.075	0.8	0.35	0.65	0.65	0.925	0.925	0.925	0.65	0.35
A_2	0.925	0.075	0.075	0.925	0.2	0.8	0.8	0.8	0.8	0.8	0.8	0.5	0.8

	C_{215}	C_{216}	C_{34}	C_{37}	C_{38}	C_{43}	C_{46}	C_{47}	C_{49}	C_{410}	C_{412}	C_{415}	C_{51}
A_1	0.925	0.925	0.65	0.925	0.65	0.925	0.8	0.925	0.5	0.5	0.925	0.925	0.925
A_2	0.8	0.8	0.5	0.35	0.5	0.8	0.35	0.65	0.65	0.65	0.8	0.8	0.8

	C_{52}	C_{53}	C_{54}	C_{55}	C_{59}	C_{510}	C_{61}	C_{63}	C_{65}	C_{67}	C_{69}	C_{73}	C_{74}
A_1	0.2	0.2	0.35	0.35	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.925
A_2	0.075	0.35	0.2	0.5	0.925	0.65	0.65	0.35	0.65	0.65	0.925	0.65	0.8

As $1/(m-1) = \frac{1}{2-1} = 1$, it is found that $Q(A_2) - Q(A_1) = 1 - 0 = 1$. Thus, the condition is satisfied.

(2) Acceptable stability in decision-making

Table 11 illustrates that A_1 also possesses the best rank for S_i and R_j. Hence, this condition is satisfied.

As such, by quantitatively evaluating the SCSS performance, companies can thereby gain some insights into how to improve the SC from the holistic view and on which area they need to exert influence. On occasions that a company is in the process of choosing a partner from these two companies, the result can also provide comprehensive suggestions. Although company X achieves the best rank for the whole system, company Y surpasses it in some areas. For instance, company Y addresses more accurate forecast and freight bills, fill rates and less product safety incidents, which stimulate better labor conditions, more customer satisfaction and operational costs reduction, whereas company X possessing higher inventory turnover and more on-time delivery reflects more efficient operations and may accommodate more economical competitiveness. In conclusion, in align with business-specific requirements and excel at one particular area, they can adjust the relative importance of each criteria group accordingly. For example, if the quality improvement field of the partner is more essential to the company, the weights of manufacturing criteria can be tuned higher and the rank can be recalculated.

Table 11 The values of S_i, R_j and Q_i and the companies' performance ranking

	A_1	A_2	Rankings
Q_i	0	1	$A_1 > A_2$
S_i	0.272	0.728	$A_1 > A_2$
R_j	0.062	0.063	$A_1 > A_2$

4.2 Sensitivity analysis

The parameter v from the VIKOR method is defined as weight of the strategy of the "majority of attributes" and the value can be taken within the interval of [0, 1] (Rao, 2008). The value is generally set to be 0.5. Due to the importance of v in the VIKOR implementation, a sensitivity analysis on v is proceeded. The value of v will be taken as 0, 0.25, 0.5, 0.75, and 1. The preceding steps of the framework remain the same.

Table 12 illustrates the sensitivity analysis results. It can be seen that with different values of v, with the same outputs from the fuzzy-AHP–DEMATEL computation, the results from VIKOR do not fluctuate. The Q_i of the two alternatives are not changed, saying the ranking remains the same, with A_1 being the best ranking. This phenomenon implies that the weights of criteria have more influence. As most sub-criteria of alternative A_1 get more scores than A_2, even v varies to change the strategy weight of the "majority of attributes", the ranking is still the same. This analysis reveals the result of our proposed framework is reliable and robust.

5 Discussion and limitations

5.1 Trade-off between economic and social dimensions

Currently there is the absence of managerial decision-making tools considering social sustainability in the SC system. This evaluation framework can make up for this deficiency. It can be generalized and adopted in various types of industries in different regions/countries since the respondents and samples were chosen randomly. There can be more alternatives added in the evaluation framework for ranking. Since Singapore is a prominent manufacturing and distribution center for multinational corporations in Southeast Asia and intends to maintain the position and attract more business, there is necessity to have a thorough understanding on the SC performance and maintain the system economic and social sustainability to promote industrial images. In virtue of diversified performance evaluation of different companies, the framework standardizes the SCSS performance measurement. Therefore, it provides sound suggestions for companies to select their coordination partners. Simultaneously, the trade-off between different elements can cultivate the overall improvement and optimize the aggregate efficiency. Furthermore, due to more awareness of corporate social responsibility, the incorporation of the social aspect into the SC performance is a significant step. This

v	Q_i		Ranking
	A_1	A_2	
0	0	1	$A_1 > A_2$
0.25	0	1	$A_1 > A_2$
0.5	0	1	$A_1 > A_2$
0.75	0	1	$A_1 > A_2$
1	0	1	$A_1 > A_2$

Table 12 Rankings for different values of v

model can furnish researchers some perspectives to establish a framework to measure a SC sustainability performance. Further, the governing institute can exploit the evaluation framework to comprehend the influence of the relevant policies on the SC sustainable performance and implement modification promptly to shepherd the SC to be more sustainable.

5.2 Influencing factors on supply chain social and economic sustainability

The weight score of each criterion can provide a benchmark tool to the stakeholders and can provide insights to the management to improve companies' sustainability (Golroudbary et al., 2019). The company's current strength can be recognized and the disadvantaged areas are detected. The results can also facilitate identifying the areas the company can capitalize on to realize more social sustainable. According to the KPI tree, the criterion, demand planning, occupies the most weight to evaluate the performance, which complies with the statement by Pathak et al. (2022). Thus, to precisely capture market trends and prevent operation disruption need more effort to achieve a better SSSC performance. The second valued criterion is distribution and delivery under social dimension, in line with the declaration of Shou et al. (2022). To maintain a good company image and high product responsibilities, an efficient distribution and delivery system is required.

More specifically, it can be seen that for the targeted Singapore-located manufacturing industry, the product safety issue is the most concerned part for the managers, followed by forecast accuracy and error. The third important is the finished goods turnover, followed by on-time pickup. This rank provides insights that the manager should strictly monitor the safety issues and operation efficacy and improve the forecast accuracy to ensure the SC sustainable smoothness and improvement.

Within the social aspect, the distribution and delivery and sales and customer relationship are observed occupying a large portion for performance evaluation. This result indicates the strategic importance of suppliers and customers. Additionally, there is implication that the focal company should select a social sustainable supplier to facilitate the company's social sustainability. Concerning the specific geographical location and commercial environment of Singapore, numerous international companies locate their global distribution center in Singapore. It may be the reason that responsive and accurate delivery is strategically important stemmed from our survey. Therefore, for a country alike Singapore, the delivery system should receive more attention and be enhanced to be more robust to guarantee the global trade, especially confronting catastrophe and public emergency. If several companies are under selection scheme, the potential partner is advised to stress the company's distribution and delivery performance. Additionally, the export control incidents have negative effects on distribution and delivery, which should be avoided to prolong the business operation. Moreover, the second most important criterion, sales and customer relationship, reflects prompt complaint management and high-standard service can advance the reputable SC system potently. Thus, a professional channel to collect and handle customers' feedback should be built and revised frequently.

Within the economic aspect, it is found that the demand planning function is of utmost importance to present the SC performance level. The forecast accuracy is paid highly attention. In view of this, the company should trace the real-time sales and demand information. In addition, managers are advised to introduce advanced technology to increase forecast accuracy. Innovation also contributes to building a better reputable SC, which is supported by the announcement of Awan (2019a). Under such

context, certain amount of investment on innovation are advised to be retained. More products meeting market needs and beneficial for supply chain operations are advised to be studied. Moreover, supply chain innovation are suggested to keep pace with the technology advancements, such as the Internet of things (IoT) and block chain.

As such, with deep understanding of the holistic reputable SC, the decision-makers could make decisions for more efficient resource allocation to achieve balance of economic and social sustainability. The benchmark model built provides an effective channel for company self-assessment. It further fosters the continuous improvement of a company and boosts the competency.

5.3 Limitations

Our research has some limitations. The sample size of manufacturing and service companies we used is relatively small. With large dataset, the results can be generalized more easily. Additionally, the upstream supplier and downstream customers are not interviewed in this study. As the factors from upstream and downstream can influence the whole SC, without consideration of them may hinder the better decision-making. Moreover, some other social sustainability factors such as employee welfare, employment quality and training hours are not included in the study.

6 Conclusion and future works

This article analyzes the social and economic sustainability performance of sustainable supply chain management and proposes an integrated fuzzy AHP–DEMATEL–VIKOR model to quantify the performance. A case study of two manufacturing companies in Singapore is presented to show how to use the proposed framework and to validate the method's practical effectiveness. The proposed framework can be generalized to various industries in various regions as the sample data is collected randomly. The novelty of this study is that the trade-off between social and economic sustainability is quantified. And this is the first study on reputable SC performance measurement in Singapore manufacturing sector. Besides, we include some indicators which are not considered in previous similar research, such as demand planning. The conclusion of this paper can be stated as follows:

- Seven social and economic criteria are identified to measure the reputable SC performance for Singapore manufacturing and service companies.
- An evaluation framework is developed to quantify the performance using the integrated fuzzy AHP–DEMATEL–VIKOR model. And the reputable SC performance of two companies are ranked on the grounds of focused part from experts.
- The influence of indicators for reputable SC performance is analyzed in details to provide advisory to decision-makers. It is found that demand planning under economic dimension and delivery and distribution under social dimension are the two most important criteria. Thus, it is an inevitable trend to precise predict market trend and maintain high-standard service and product quality.
- The product safety incidents frequency and export control safety incidents frequency are two valued indicators, implying that the labor condition and product responsibility have strong influence on the supply chain social sustainability, which should be paid attention.

For future studies, more companies can be involved other than manufacturing and service companies to extend and refine the evaluation tool to various industries. Additionally, the upstream and downstream parties can be considered more deeply simultaneously to have a better understanding of the whole reputable SC performance, as more indicators such as employee's welfare will be involved and explored. Interviews can be conducted with them for a first-hand information. Furthermore, the environmental aspect should be included as well to achieve more comprehensive and complete sustainability measurement. In addition, in future it is possible to consider simulation techniques to facility performance measurement akin the study of Golroudbary et al. (2019). The stakeholder's behavior can be simulated based on surveys.

Appendix 1: Acronyms in the paper

SC	Supply chain
SSCM	Sustainable supply chain management
SSCS	Supply chain social sustainability
SSSC	Social sustainable supply chain
KPI	Key Performance Indicator
AHP	Analytic hierarchy process
DEMATEL	Decision-making trial and evaluation laboratory
VIKOR	Vlekriterijumsko KOmpromisno Rangiranje
MCDM	Multi-criteria decision-making
BSC	Balanced scorecard
PROMETHEE	Preference ranking organization method for enrichment evaluations
SSC	Sustainable supply chain
FCM	Fuzzy cognitive map
DEA	Data envelopment analysis
BWM	Best–worst method

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