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Enhancing corporate knowledge management and sustainable development: An inter-dependent hierarchical structure under linguistic preferences

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ABSTRACT

With the United Nations' announcement of the 2030 sustainable development goals agenda, the electronic industry is striving to improve corporate sustainability performance. Studies have attempted to consider knowledge management to promote corporate sustainability performance. However, the possible linkages and potential benefits for bridging knowledge management and corporate sustainability performance are still lacking in previous discussions. To address this gap, this study proposes a hybrid method that integrates a fuzzy synthetic method with an analytical network process to develop an inter-dependent hierarchical framework. The results indicate that the relation, operation and economy aspects must align with the priority goal of achieving better corporate sustainability performance. Improvements of these aspects rely on the knowledge management of developing rigid external collaboration, adopting information technology-supported processes and expanding capital for developing knowledge management. This study contributes to (1) bridging knowledge management and corporate sustainability performance; (2) providing a hybrid method to develop a hierarchical framework; and (3) giving specific directions for guiding improvements. Theoretical and managerial implications are discussed.

1. Introduction

With the United Nations' declaration of the 2030 sustainable development goals agenda, the electronic industry is striving to recycle its product series to reach 100% reuse from waste disposals. Therefore, corporate sustainability performance (CSP) plays an important role in leading electronic firms to pursue sustainability. Several studies have demonstrated that CSP enables firms to take full advantage of their resources, reduce waste, enhance their economic performance and promote their social reputation (Tseng et al., 2008; Shi et al., 2017). However, CSP involves a complex interrelationship that requires a hierarchical framework to guide improvements. Few studies have attempted to consider this inter-dependence in formulating a framework (Tseng et al., 2017). Although Robinson et al. (2006) attempted to consider the role of knowledge management (KM) in promoting CSP in the construction industry context by proposing a five-stage roadmap, their study lacks a precise inter-dependence hierarchical framework to guide firms in strategic development.

CSP is considered a corporate activity in exploring the balance of sustainability. It must take economic, environmental and social aspects into account with respect to interrelationships over time while addressing a firm's systems and fulfilling the expectations of stakeholders (Lozano, 2012). Prior studies highlighted the essential need to adopt KM in addressing CSP because the technology is rapidly changing (Gaziulusoy et al., 2013; García-Álvarez, 2014). KM enables the transfer of useful information and intellectual assets and permanently preserves the value of firms by enhancing CSP (Lim et al., 2017). KM has been considered an important approach to conquer the issue of sustainability; however, the possible linkages and potential benefits of bridging KM with CSP remain vague (Ruhanen, 2008; Bolis et al., 2012).

Shi et al. (2017) proposed an inter-dependent closed-loop hierarchical framework of CSP by considering the aspects of the triple bottom line. Tseng et al. (2017) adopted the resource-based view to formulate a hierarchical framework to assess CSP. Despite these studies'

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attempts to formulate a hierarchical framework for CSP, the bridge between KM and CSP still requires further discussion. Nisar et al. (2019) noted that KM enables the generation of an effective strategy by considering social media. However, extracting information from related websites and including these social media data in decision-making processes to enhance accuracy requires an appropriate approach (Culnan et al., 2010; Chan et al., 2016). Tseng et al. (2018) showed that firms struggle to acquire a professional understanding of social media that allows them to reap its benefits.

To overcome these gaps, this study used a web crawler to gather the accumulating frequencies from social media and transfer them into entropy weights. The majority of previous studies adopted classic statistical approaches to develop a framework without addressing the interrelationships among the proposed measures to reflect the real situation (Dočekalová et al., 2017). This study proposes a hybrid method that integrates the fuzzy synthetic method (FSM) and analytical network process (ANP) to develop an inter-dependent hierarchical framework for CSP with the following objectives: (1) structuring a reliable hierarchical framework to bridge CSP and KM; (2) considering the interrelationships in the performance assessments; and (3) providing valid guidelines for improvements.

The rest of this study is organized as follows. A literature review, proposed methods and proposed measures are discussed in Section 2. Section 3 offers details of the hybrid method and proposed analytical procedures. The case background and analytical results are presented in Section 4. Section 5 addresses the theoretical and managerial implications. Conclusions, contributions and research limitations are presented in the final section.

2. Literature review

This section provides a comprehensive literature review, proposed methods and proposed measures to explain the theoretical basis of this study.

2.1. KM

Knowledge is an effective instrument that enables an increase in the capacity to assist firms in managing several processes. Duhon (1998) defined "*KM as an integrated approach to identify, capture, evaluate, retrieve and share all information with the forms of database, document, policy, procedure and formerly uncaptured expertise and experience in individual workers*." Thus, launching these practices requires corporate knowledge resources to manage activities to improve performance (Andreeva and Kianto, 2012; Anand et al., 2015). Previous studies provided relevant support to increase the understanding of implementation; however, very few studies have addressed the issue of how to utilize KM to promote CSP in the long run (Inkinen et al., 2015).

Prior KM studies have moved from a concentration within the firm and extended beyond traditional firm boundaries. For example, Ko et al. (2005) revealed the importance of knowledge transfers between external consultants and customers in the process of enterprise resource planning implementation. Malhotra et al. (2005) noted that KM in terms of creation enables the generation of absorptive capacity in the supply chain. Recent studies relating to KM have mainly focused on the measurement of its impact by considering complex decision-making processes (Arnold et al., 2006). Choi et al. (2010) discussed KM with regard to sharing applications and team performance. Huang and Zhang (2016) investigated the participation of KM in the improvement of career development and job performance. Some studies have considered KM as an approach to assist firms in obtaining innovation (Obeidat et al., 2016; Wallin et al., 2017).

Table 1
Proposed attributes.

Aspects		Criteria	
A1	Economy	C1	Acquiring financial data
		C2	Exchanging service knowledge
		C3	Reducing knowledge management costs
		C4	Expanding capital for developing KM
A2	Environment	C5	Minimizing and recovering waste
		C6	Learning competence in dealing with environmental issues
		C7	Green purchasing
		C8	Added value of enhanced environmental awareness
A3	Society	C9	Molding good working conditions
		C10	Enhancing knowledge information security
		C11	Reinforcing customer knowledge
		C12	Offering employee training and education
A4	Relation	C13	Improving communication channels
		C14	Encouraging participation and feedback in making decision
		C15	Developing external collaboration
		C16	Improving transparency
A5	Resilience	C17	Searching organizational learning path
		C18	Innovating knowledge storage
		C19	Establishing management approaches
		C20	Sourcing flexibility in knowledge management
A6	Long term	C21	Sharing information/knowledge
		C22	Generating joint knowledge
		C23	Converting competitive intelligence into plans of action
A7	Operations	C24	Integrating knowledge and information flow
		C25	Utilizing knowledge management in reducing the lead time
		C26	Adopting IT-supported processes
		C27	Maintaining internal connections

2.2. CSP

Many studies have addressed the issues of CSP through the triple bottom line concept, which involves economic, environmental and social aspects (Dočekalová et al., 2017; Tseng, 2017; Vildåsen et al., 2017). However, Wu et al. (2016) argued that the economic, environmental and social aspects are insufficient to cover the entire concept of sustainability. Moreover, Lozano (2012) emphasized that firms must consider operations and processes for improving CSP efficiently. Ahi and Searcy (2013) showed that resilience can support the fulfillment of diversity needs, address a variety of concerns among stakeholders and afford a buffer to mitigate the occurrence of risk. Wolf (2014) noted that management and strategy for achieving long-term development are essential to improve CSP for planning-based firms. Relations with customers, shareholders, suppliers, partner firms, authorities, society and stakeholders must be concerned with obtaining better performance (Baumgartner and Rauter, 2017). This study attempts to integrate these aspects to provide a comprehensive consideration of the development of an inter-dependent hierarchical framework to support the theoretical basis.

The purpose of CSP is to take the environment into account rather than to adopt a single, short-term economic focus in developing sustainability (Dao et al., 2011; Amini and Bienstock, 2014). Previous studies concentrated on the discussion of economic, social and environmental aspects (Tseng et al., 2008; Shi et al., 2017). Though these aspects have been demonstrated to have a direct impact on sustainable development, arguments and debates over the lack of an extensive theoretical basis continue (Seuring and Müller, 2008; Vildåsen et al., 2017). This situation requires an exploration of the decisive aspects to

Table 2
Entropy Weight Calculation from Web Crawler.

	Website Address	Huawei Technologies Co., Ltd. www.huawei.com	China Telecom Corporation www.chinatelecom.com.cn	Lenovo Group Ltd. www.lenovo.com.cn	Total
	Number of Pages	22.064	16.457	38,125	76,646
Frequency	Economy	3,420	2,630	2,510	8,560
	Environment	3,083	12,000	255	15,338
	Society	11,565	4,749	4,364	20,678
	Relation	3,707	209	259	4,175
	Resilience	4,000	207	1,312	5,519
	Long term	5,609	9,803	265	15,677
	Operation	3,289	209	250	3,748
Normalized	Economy	0.400	0.307	0.293	0.116
	Environment	0.201	0.782	0.017	0.208
	Society	0.559	0.230	0.211	0.281
	Relation	0.888	0.050	0.062	0.057
	Resilience	0.725	0.038	0.238	0.075
	Long term	0.358	0.625	0.017	0.213
	Operation	0.878	0.056	0.067	0.051
Entropy	Economy	0.188	0.186	0.185	0.129
	Environment	0.166	0.099	0.035	0.168
	Society	0.167	0.174	0.169	0.183
	Relation	0.054	0.077	0.089	0.084
	Resilience	0.120	0.063	0.176	0.100
	Long term	0.189	0.151	0.035	0.169
	Operation	0.059	0.083	0.093	0.078
Entropy weight	Economy	0.134	0.132	0.131	**0.143**
	Environment	0.138	0.146	0.155	0.137
	Society	0.138	0.134	0.134	0.134
	Relation	0.156	0.150	0.147	0.150
	Resilience	0.145	0.152	0.133	0.148
	Long term	0.134	0.138	0.155	0.136
	Operation	0.155	0.149	0.146	0.151

Note: The gray-shaded column represents the values calculated by integrating the data from the three firms.

reinforce the theoretical support and identify significant evidence to increase the validity of CSP (Liu et al., 2012; Tseng et al., 2017).

Previous studies also strived to explore different theories to explain CSP. For example, Linnenluecke and Griffiths (2010) provided a measurement of the link between organization culture and CSP by assessing the constitution of sustainability-oriented culture. Johnson et al. (2018) considered stakeholder engagements as a vital tool for CSP and investigated the influence of customer segments on stakeholder engagement in many aspects against the background of corporate sustainability based on a survey of German firms. However, few studies have discussed the possible links and benefits of bridging KM and CSP (Bolis et al., 2012; Ruhanen, 2008). Thus, this study attempts to explore a theoretical framework for electronic firms to improve their CSP performance through KM.

2.3. Proposed hybrid method

FSM is not only used to address the complicated interrelationships among the proposed measures but also to simplify this complicated relation into a systematic framework while considering multiple dimensions (Gautam and Nagendra, 2018). ANP is adopted to structure the hierarchy with ranks based on pairwise comparison to consider the dependencies and feedback of the criteria (Pang and Bai, 2013). Hence, this study proposes FSM-ANP to (1) reduce the assessment time for experts to enhance the consistency of the analytical results; (2) transfer the interrelationship into a hierarchical framework to ensure that improvements align with the expected goal; (3) integrate social media data into the decision-making process to provide a comprehensive consideration; and (4) eliminate subjective opinions to promote the accuracy of decision-making.

Hu et al. (2016) conducted FSM to develop a program organization performance index for assessing Chinese construction megaprojects. Ulubeyli (2017) evaluated the cement industry's competitiveness by employing FSM. Xu et al. (2017) proposed a hybrid method based on the dynamic FSM to generate an air quality furcating warning system. Tseng et al. (2017) integrated the FSM with a decision-making trial and evaluation laboratory to assess the CSP for the Taiwanese textile industry. Li et al. (2018) utilized stakeholder theory with FSM to assess policy effectiveness for contaminated site management. These studies demonstrate that FSM is an efficient and effective approach to decomposing complexity into systematic assessment and has been widely applied in diverse industries.

ANP is broadly implemented to solve decision-making problems. Büyüközkan (2011) presented a decision-making framework to determine decisive factors for achieving a sustainable supply chain through ANP. Tseng et al. (2015) constructed a generalized quantitative evaluation model based on the fuzzy Delphi method and ANP by considering the interdependence and fuzziness of subjective measures in sustainable supply chain management. Shi et al. (2017) assessed CSP, addressed interdependent relationships in a closed-loop hierarchical structure and provided a ranking of the proposed attributes by revising the traditional ANP.

2.4. Proposed attributes

The aspect of economy (A1) is usually considered critical for attaining CSP because profit motivates the development of firms. Therefore, acquiring financial data (C1) and exchanging service knowledge (C2) are related to KM in enabling firms to improve their economic performance (Chen et al., 2012; Patil and Kant, 2014; Lai et al., 2014). Consequently, reducing KM cost (C3) and expanding capital for developing KM (C4) offer advantages for firms to improve the

Table 3
Sample of 35 Experts' Assessments under Goal.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	E31	E32	E33	E34	E35
A1	5	2	3	2	4	3	2	1	1	2	3	2	5	5	3	4	2	3	2	4	3	1	4	5	4	1	5	3	3	5	3	1	1	5	4
A2	3	4	2	3	4	5	3	4	3	3	1	5	2	1	5	3	4	1	2	2	4	2	3	2	4	2	1	5	3	3	1	2	2	3	4
A3	1	5	1	2	3	5	1	5	5	1	4	1	5	4	1	1	1	3	2	4	3	2	3	2	3	3	4	5	2	4	4	2	5	2	2
A4	4	5	2	1	3	5	4	5	5	3	5	4	1	5	2	4	1	5	5	5	4	2	5	4	3	4	2	2	3	4	2	5	3	2	5
A5	1	4	4	5	4	4	2	2	1	4	1	4	1	1	4	5	1	2	5	4	5	2	2	3	3	2	2	1	4	4	1	3	4	2	1
A6	4	4	2	1	5	5	2	2	1	1	2	1	1	4	4	4	4	1	1	5	4	3	5	2	4	3	2	2	1	5	5	3	3	1	5
A7	4	4	1	1	1	5	2	4	4	1	2	4	1	4	5	2	4	1	4	4	4	1	1	5	3	5	2	2	5	4	5	5	1	3	5

economic conditions needed to achieve economic sustainability (Wu, 2008; Martinez-Conesa et al., 2017).

The aspect of the environment (A2) affects the strategy development of firms and their resource allocation (Matos and Hall, 2007). Minimizing and recovering waste (C5) and gaining competence in dealing with environmental issues (C6) make firms able to address complex environmental problems (Fiksel, 1996; Hart, 1997; Alegre et al., 2013). Knowledge of green purchasing (C7) and the added value of enhanced environmental awareness (C8) can be used to prevent negative impacts on the environment (Eltayeb et al., 2011; Jasimuddin and Zhang, 2011).

Society (A3) might generate pressure if firms' CS performance does not fulfill public expectations (Wu et al., 2016). Developing good working conditions (C9) and offering employee training and education (C12) are effective ways to promote employees' satisfaction and reduce social pressure (Blumenberg et al., 2009; Cao and Zhang, 2011; Chardine-Baumann and Botta-Genoulaz, 2014). In addition, social pressure might result from information that is exposed, thus enhancing the value of knowledge information security (C10) and protecting public intangible wealth as a necessary action (Patil and Kant, 2014). Reinforcing customer knowledge (C11) plays an important role in enhancing social understanding (Liao et al., 2008; Patil and Kant, 2014). Once society acknowledges a firm's activities, the firm can succeed in acquiring a good reputation.

Relations (A4) with stakeholders can efficiently assist firms in achieving sustainability at the corporate level (Dočekalová and Kocmanová, 2016). Firms must consider their present and future relationships with stakeholders, improve communication channels (C13) and encourage stakeholders' participation and feedback in making decisions (C14) to maintain a solid relationship with customers (Lai et al., 2014; Baumgartner and Rauter, 2017). However, developing external collaborations (C15) and improving transparency (C16) are normally omitted in CSP (Noruzy et al., 2013; Lim et al., 2017).

Firms must satisfy stakeholders and improve their profitability, competitiveness and resilience over the short and long term to achieve sustainability (Ahi and Searcy, 2013). Thus, resilience (A5) can be considered a buffer for firms when they encounter risk and uncertainty. Identifying an organizational learning path (C17) and innovating knowledge storage (C18) are useful procedures for generating resilience (Alegre et al., 2013; Gulati, 2015). Moreover, establishing management approaches (C19) and sourcing flexibility in KM (C20) are long-term tasks for achieving CSP (Gold et al., 2001; Stevenson and Spring, 2007; Lai et al., 2014).

Violeta and Gheorghe (2009) revealed that firms tend to have long-term (A6) goals for their commitment to developing sustainability. For long-term sustainability, a firm must possess competitiveness, and sharing information/knowledge (C21) is a vital process for expanding the knowledge of everyone within a firm (Chen et al., 2000; Wu et al., 2016; Lim et al., 2017). In addition, generating joint knowledge (C22) and converting competitive intelligence into plans of action (C23) are important practices for pursuing long-term CSP (Malhotra et al., 2005; Iacono et al., 2012; Noruzy et al., 2013).

Operations (AS7) were missing from previous sustainability studies (Wu et al., 2016). Tahir and Darton (2010) and Zailani et al. (2012) emphasized that operations must be considered in efforts to improve CSP. Integrating knowledge and information flow (C24) enables the generation of a bridge to connect different information sources and gather useful knowledge to address operational problems (Al-Mutawah et al., 2009; Noruzy et al., 2013). Utilizing KM to reduce lead time (C25) and adopting IT-supported processes (C26) can make operations more efficient (Wu, 2008; Vickery et al., 2010). Maintaining internal connections (C27) can reduce operational conflicts and defects to increase CSP. Consequently, this study selects 7 aspects with 27 criteria to bridge CSP and KM in developing an inter-dependent framework (see Table 1).

Table 4
The Membership Function of Criteria under Goal and Aspects.

	Goal						A1		
	Value	Membership Function					Value	Membership Function	
C1	2.943	0.229	0.229	0.200	0.057	0.286	3.171	0.200	0.143
C2	3.086	0.171	0.229	0.229	0.086	0.286	2.886	0.314	0.114
C3	3.000	0.200	0.200	0.200	0.200	0.200	2.800	0.229	0.257
C4	3.400	0.143	0.171	0.114	0.286	0.286	2.943	0.171	0.143
C5	2.857	0.229	0.143	0.343	0.114	0.171	2.971	0.200	0.171
C6	3.029	0.257	0.143	0.171	0.171	0.257	3.000	0.114	0.314
C7	3.057	0.114	0.257	0.286	0.143	0.200	3.114	0.171	0.143
C8	3.429	0.143	0.086	0.200	0.343	0.229	3.171	0.171	0.143
C9	2.800	0.229	0.257	0.171	0.171	0.171	2.657	0.229	0.229
C10	2.857	0.200	0.343	0.057	0.200	0.200	2.343	0.371	0.229
C11	3.200	0.114	0.257	0.171	0.229	0.229	3.114	0.171	0.200
C12	3.000	0.171	0.229	0.200	0.229	0.171	2.914	0.200	0.314
C13	2.943	0.257	0.171	0.171	0.171	0.229	3.114	0.171	0.143
C14	3.114	0.200	0.143	0.171	0.314	0.171	3.114	0.143	0.229
C15	3.257	0.171	0.086	0.343	0.114	0.286	3.000	0.200	0.229
C16	3.143	0.086	0.314	0.143	0.286	0.171	2.886	0.200	0.171
C17	3.029	0.229	0.171	0.171	0.200	0.229	3.543	0.114	0.171
C18	3.000	0.286	0.114	0.200	0.114	0.286	2.543	0.343	0.171
C19	3.029	0.171	0.200	0.229	0.229	0.171	3.114	0.200	0.171
C20	3.571	0.086	0.200	0.143	0.200	0.371	3.257	0.114	0.171
C21	3.029	0.114	0.229	0.371	0.086	0.200	2.943	0.257	0.114
C22	2.714	0.257	0.286	0.114	0.171	0.171	3.229	0.143	0.229
C23	2.600	0.400	0.057	0.171	0.286	0.086	3.200	0.171	0.200
C24	2.914	0.200	0.171	0.200	0.371	0.057	2.971	0.200	0.171
C25	3.114	0.229	0.229	0.057	0.171	0.314	3.114	0.229	0.114
C26	3.286	0.057	0.143	0.371	0.314	0.114	2.886	0.257	0.171
C27	2.886	0.143	0.314	0.200	0.200	0.143	3.029	0.143	0.200

	A1			A2						A3
	Membership Function			Value	Membership Function					Value
C1	0.229	0.143	0.286	2.971	0.171	0.257	0.200	0.171	0.200	2.429
C2	0.143	0.229	0.200	3.600	0.029	0.229	0.200	0.200	0.343	3.514
C3	0.200	0.114	0.200	3.029	0.229	0.143	0.229	0.171	0.229	3.343
C4	0.343	0.257	0.086	3.057	0.229	0.114	0.257	0.171	0.229	2.886
C5	0.257	0.200	0.171	2.571	0.257	0.286	0.143	0.257	0.057	3.086
C6	0.200	0.200	0.171	3.200	0.143	0.114	0.286	0.314	0.143	2.857
C7	0.286	0.200	0.200	3.200	0.229	0.171	0.114	0.143	0.343	3.286
C8	0.229	0.257	0.200	2.914	0.229	0.171	0.229	0.200	0.171	3.086
C9	0.286	0.171	0.086	3.400	0.114	0.114	0.257	0.286	0.229	2.857
C10	0.171	0.143	0.086	2.914	0.286	0.114	0.257	0.086	0.257	2.914
C11	0.171	0.257	0.200	3.257	0.171	0.200	0.114	0.229	0.286	3.600
C12	0.143	0.057	0.286	2.886	0.200	0.200	0.286	0.143	0.171	3.029
C13	0.200	0.371	0.114	3.000	0.086	0.343	0.257	0.114	0.200	2.943
C14	0.171	0.286	0.171	3.286	0.200	0.171	0.114	0.171	0.343	2.743
C15	0.114	0.286	0.171	3.029	0.229	0.143	0.171	0.286	0.171	3.057
C16	0.286	0.229	0.114	3.171	0.143	0.200	0.200	0.257	0.200	2.771
C17	0.114	0.257	0.343	2.971	0.286	0.086	0.200	0.229	0.200	2.829
C18	0.200	0.171	0.114	2.800	0.257	0.257	0.114	0.171	0.200	2.914
C19	0.171	0.229	0.229	2.886	0.286	0.143	0.171	0.200	0.200	2.971

(continued on next page)

Table 4 (*continued*)

	A1			A2						A3
	Membership Function			Value	Membership Function					Value
C20	0.257	0.257	0.200	2.857	0.171	0.257	0.257	0.171	0.143	3.171
C21	0.229	0.229	0.171	2.914	0.257	0.229	0.086	0.200	0.229	3.343
C22	0.171	0.171	0.286	3.457	0.143	0.171	0.114	0.229	0.343	2.857
C23	0.171	0.171	0.286	2.571	0.314	0.200	0.200	0.171	0.114	2.686
C24	0.200	0.314	0.114	2.914	0.171	0.143	0.371	0.229	0.086	3.171
C25	0.171	0.286	0.200	2.886	0.171	0.200	0.371	0.086	0.171	3.171
C26	0.171	0.229	0.171	2.886	0.143	0.314	0.171	0.257	0.114	3.143
C27	0.314	0.171	0.171	3.029	0.229	0.200	0.143	0.171	0.257	2.714

	A3					A4				
	Membership Function					Value	Membership Function			
C1	0.371	0.200	0.200	0.086	0.143	3.114	0.143	0.200	0.257	0.200
C2	0.143	0.086	0.171	0.314	0.286	2.829	0.171	0.229	0.314	0.171
C3	0.086	0.257	0.171	0.200	0.286	3.086	0.257	0.143	0.143	0.171
C4	0.257	0.229	0.114	0.171	0.229	3.086	0.200	0.143	0.200	0.286
C5	0.229	0.171	0.114	0.257	0.229	2.829	0.257	0.171	0.229	0.171
C6	0.257	0.171	0.200	0.200	0.171	3.057	0.143	0.257	0.229	0.143
C7	0.143	0.200	0.143	0.257	0.257	2.686	0.314	0.171	0.200	0.143
C8	0.114	0.200	0.314	0.229	0.143	3.143	0.143	0.229	0.200	0.200
C9	0.200	0.200	0.314	0.114	0.171	2.686	0.286	0.229	0.171	0.143
C10	0.229	0.200	0.171	0.229	0.171	3.229	0.114	0.314	0.086	0.200
C11	0.057	0.171	0.171	0.314	0.286	3.314	0.114	0.171	0.286	0.143
C12	0.257	0.200	0.086	0.171	0.286	3.114	0.229	0.114	0.171	0.286
C13	0.200	0.257	0.143	0.200	0.200	3.086	0.143	0.200	0.257	0.229
C14	0.200	0.286	0.229	0.143	0.143	3.114	0.143	0.143	0.286	0.314
C15	0.143	0.229	0.257	0.171	0.200	2.943	0.200	0.257	0.171	0.143
C16	0.343	0.143	0.114	0.200	0.200	2.857	0.229	0.257	0.114	0.229
C17	0.257	0.143	0.257	0.200	0.143	2.829	0.200	0.286	0.200	0.114
C18	0.257	0.200	0.143	0.171	0.229	2.857	0.229	0.200	0.171	0.286
C19	0.171	0.229	0.229	0.200	0.171	3.000	0.314	0.086	0.143	0.200
C20	0.114	0.286	0.171	0.171	0.257	3.229	0.200	0.143	0.114	0.314
C21	0.114	0.200	0.171	0.257	0.257	3.143	0.200	0.200	0.171	0.114
C22	0.257	0.229	0.114	0.200	0.200	2.714	0.229	0.286	0.171	0.171
C23	0.229	0.229	0.257	0.200	0.086	3.057	0.143	0.229	0.200	0.286
C24	0.286	0.086	0.114	0.200	0.314	3.086	0.143	0.257	0.171	0.229
C25	0.171	0.200	0.200	0.143	0.286	2.629	0.257	0.200	0.286	0.171
C26	0.143	0.229	0.200	0.200	0.229	3.257	0.114	0.171	0.257	0.257
C27	0.257	0.257	0.171	0.143	0.171	2.829	0.229	0.229	0.200	0.171

	A4	A5						A6		
	Membership Function	Value	Membership Function					Value	Membership Function	
C1	0.200	3.286	0.200	0.171	0.086	0.229	0.314	2.771	0.171	0.257
C2	0.114	2.600	0.343	0.229	0.086	0.171	0.171	3.457	0.086	0.086
C3	0.286	2.943	0.200	0.200	0.229	0.200	0.171	3.000	0.143	0.286
C4	0.171	3.229	0.143	0.143	0.286	0.200	0.229	2.943	0.143	0.257
C5	0.171	3.057	0.229	0.114	0.171	0.343	0.143	2.800	0.257	0.143
C6	0.229	2.971	0.143	0.257	0.286	0.114	0.200	3.057	0.171	0.200

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Table 4 (*continued*)

	A4	A5						A6		
	Membership Function	Value	Membership Function					Value	Membership Function	
C7	0.171	3.171	0.200	0.171	0.171	0.171	0.286	3.257	0.114	0.257
C8	0.229	3.543	0.086	0.171	0.114	0.371	0.257	2.886	0.257	0.200
C9	0.171	2.914	0.257	0.143	0.229	0.171	0.200	3.114	0.200	0.143
C10	0.286	3.257	0.143	0.257	0.086	0.229	0.286	2.429	0.314	0.286
C11	0.286	3.000	0.171	0.143	0.343	0.200	0.143	3.057	0.229	0.143
C12	0.200	2.914	0.229	0.114	0.314	0.200	0.143	3.257	0.143	0.257
C13	0.171	3.057	0.171	0.229	0.200	0.171	0.229	3.200	0.171	0.143
C14	0.114	3.086	0.229	0.171	0.200	0.086	0.314	3.171	0.171	0.143
C15	0.229	2.743	0.257	0.200	0.200	0.229	0.114	2.914	0.171	0.229
C16	0.171	3.057	0.143	0.200	0.343	0.086	0.229	2.943	0.200	0.200
C17	0.200	3.000	0.200	0.086	0.400	0.143	0.171	3.229	0.171	0.086
C18	0.114	3.257	0.200	0.114	0.171	0.257	0.257	2.686	0.229	0.143
C19	0.257	2.971	0.200	0.200	0.229	0.171	0.200	2.800	0.143	0.314
C20	0.229	2.914	0.257	0.086	0.257	0.286	0.114	2.829	0.286	0.114
C21	0.314	3.286	0.200	0.114	0.171	0.229	0.286	3.000	0.200	0.171
C22	0.143	2.971	0.114	0.400	0.057	0.257	0.171	3.171	0.200	0.257
C23	0.143	2.943	0.257	0.200	0.171	0.086	0.286	3.743	0.114	0.086
C24	0.200	2.886	0.171	0.286	0.200	0.171	0.171	2.714	0.229	0.200
C25	0.086	3.057	0.200	0.257	0.114	0.143	0.286	3.143	0.086	0.286
C26	0.200	3.029	0.114	0.343	0.200	0.086	0.257	2.914	0.286	0.114
C27	0.171	2.886	0.257	0.171	0.171	0.229	0.171	2.971	0.229	0.286

	A6			A7						MC Rank under Goal
	Membership Function			Value	Membership Function					
C1	0.229	0.314	0.029	2.914	0.200	0.229	0.229	0.143	0.200	19
C2	0.314	0.314	0.200	3.200	0.143	0.171	0.257	0.200	0.229	10
C3	0.171	0.229	0.171	3.371	0.143	0.171	0.200	0.143	0.343	16
C4	0.257	0.200	0.143	2.971	0.143	0.257	0.229	0.229	0.143	3
C5	0.229	0.286	0.086	2.714	0.314	0.229	0.086	0.171	0.200	24
C6	0.200	0.257	0.171	3.229	0.171	0.171	0.229	0.114	0.314	12
C7	0.200	0.114	0.314	3.057	0.171	0.229	0.171	0.229	0.200	11
C8	0.114	0.257	0.171	2.971	0.200	0.171	0.229	0.257	0.143	2
C9	0.200	0.257	0.200	2.714	0.257	0.286	0.057	0.286	0.114	25
C10	0.114	0.229	0.057	3.486	0.143	0.143	0.114	0.286	0.314	23
C11	0.229	0.143	0.257	3.314	0.143	0.143	0.143	0.400	0.171	6
C12	0.114	0.171	0.314	3.143	0.229	0.171	0.086	0.257	0.257	17
C13	0.200	0.286	0.200	2.943	0.171	0.286	0.143	0.229	0.171	20
C14	0.229	0.257	0.200	2.971	0.200	0.229	0.171	0.200	0.200	8
C15	0.257	0.200	0.143	3.143	0.229	0.114	0.171	0.257	0.229	5
C16	0.229	0.200	0.171	3.000	0.200	0.114	0.314	0.229	0.143	7
C17	0.314	0.200	0.229	3.343	0.114	0.171	0.229	0.229	0.257	13
C18	0.400	0.171	0.057	3.286	0.200	0.114	0.143	0.286	0.257	18
C19	0.229	0.229	0.086	3.257	0.171	0.171	0.200	0.143	0.314	14
C20	0.257	0.171	0.171	3.229	0.086	0.200	0.229	0.371	0.114	1

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Table 4 (*continued*)

	A6			A7						MC Rank under Goal
	Membership Function			Value	Membership Function					
C21	0.286	0.114	0.229	3.029	0.143	0.229	0.257	0.200	0.171	15
C22	0.086	0.086	0.371	3.314	0.229	0.057	0.229	0.143	0.343	26
C23	0.143	0.257	0.400	2.857	0.257	0.200	0.200	0.114	0.229	27
C24	0.257	0.257	0.057	2.829	0.286	0.171	0.143	0.229	0.171	21
C25	0.257	0.143	0.229	3.257	0.229	0.086	0.143	0.286	0.257	9
C26	0.200	0.200	0.200	2.543	0.257	0.286	0.200	0.171	0.086	4
C27	0.057	0.143	0.286	3.200	0.143	0.229	0.114	0.314	0.200	22

3. Method

Qualitative data contain considerable meaningful information; however, the qualitative feature generates several barriers to integration with social media data in terms of reliability and validity. To overcome these gaps, a detailed analytical process of the proposed hybrid method is discussed in this section.

3.1. Social media data collection and transformation process

Firms strive to improve their reputation by announcing their performance/information on their official websites. However, this information contains highly qualitative features that cannot be directly integrated with quantitative analysis. Hence, this study adopts a web crawler to collect the frequencies. These frequencies from the websites involve ambiguous and gray information that must be transformed into entropy weights to consider the effects. Entropy weights represent the level of disorganization within a system, which is an objective method to compute weights based on the information of indicators (Mao et al., 2016; Wu et al., 2017). The following content addresses the transformation processes.

Assume that there are α terms, and the obtained frequencies can be presented as β_t, $t = 1,2, \ldots,\alpha$. These frequencies β_t must be normalized in advance through the following equation because they still exist as qualitative features:

$$\overline{\beta_t} = \frac{\beta_t}{\sum_{t=1}^{\alpha} \beta_t} \tag{1}$$

Subsequently, the normalized frequencies must be transferred to entropy by applying the following equation:

$$\beta_t^e = -[\ln(\alpha)]^{-1} \times \left[\sum_{t=1}^{\alpha} \overline{\beta_t} \ln(\overline{\beta_t}) \right] \tag{2}$$

where β_t^e represents the entropy for a certain indicator. An indicator with a smaller β_t^e value means that this indicator is more important and has higher weight (Ding et al., 2017).

Once the entropy is obtained, the following equation can assist in generating the entropy weight β_t^e:

$$\beta_t^e = \frac{1 - \beta_t^e}{\sum_{t=1}^{\alpha} (1 - \beta_t^e)} \tag{3}$$

where $1 - \beta_t^e$ represents the degree of divergence.

3.2. FSM-ANP considering the qualitative information

Suppose there are k experts who assess the performance of r number of criteria under goal G, and the assessment matrix can be expressed as $[a_{ij}]_{k\times r}^{G}$. Therefore, a_{ij} adopts five linguistic preferences to assess performance: very low (VL), low (L), medium (M), high (H) and very high (VH). Then, these preferences must be transferred into corresponding fuzzy synthetic scales (see Appendix 1) for further calculations.

Based on these scales, a_{ij} must be rearranged to compute the frequencies through the following equation:

$$[a_c^G]_{1\times 5} = [a_{c1}^G, a_{c2}^G, a_{c3}^G, a_{c4}^G, a_{c5}^G] \tag{4}$$

These accumulating frequencies must be normalized through the following equation:

$$[\bar{a}_c^G]_{1\times 5} = \left[\frac{a_{c1}^G}{k}, \frac{a_{c2}^G}{k}, \frac{a_{c3}^G}{k}, \frac{a_{c4}^G}{k}, \frac{a_{c5}^G}{k} \right] \tag{5}$$

These weightings require the adoption of the following equation to obtain the crisp value under goal:

$$\bar{a}_{cd}^G = 1 \times \frac{a_{c1}^G}{k} + 2 \times \frac{a_{c2}^G}{k} + 3 \times \frac{a_{c3}^G}{k} + 4 \times \frac{a_{c4}^G}{k} + 5 \times \frac{a_{c5}^G}{k} \tag{6}$$

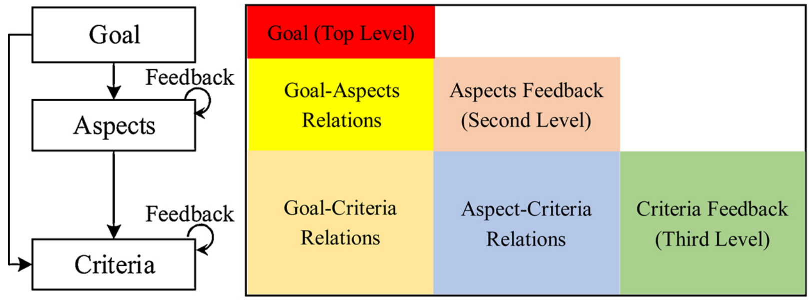

Fig. 1. The Structure of FSM-ANP Considering the Interrelationships in the Supermatrix.

In addition, the measurement criticality (MC) is used to evaluate how the criteria are correlated with the goal. A geometric average is proposed to obtain the MC using the following equation:

$$MC_i = \sqrt[n]{\prod_{i=1}^{n} \bar{a}_{cd}^{G}} \tag{7}$$

To confirm the consistency of these assessments, this study also checks the consistency index (*CI*) and the consistency ratio (*CR*) from the ANP method using the following equations:

$$CI = \frac{\lambda_{\max} - 1}{n - 1} \tag{8}$$

$$CR = \frac{CI}{RI} \tag{9}$$

where $\lambda_{\max}$ is acquired by utilizing MATLAB, and n represents the matrix size and value of *RI* defined as the average random consistency index (relevant figures can be found in Appendix 2). If $CR < 0.1$, the assessment possesses consistency; otherwise, the assessment must be rearranged to achieve consistency.

Subsequently, the factor weightings must be generated through the following equation:

$$\bar{a}_{cd}^{G} = \frac{\bar{a}_{cd}^{G}}{\sum_{c=1}^{G} \bar{a}_{cd}^{G}}, \quad d = 1,2, \ldots, r \tag{10}$$

where G represents the assigned group based on the category in Table 1.

The membership function of the goal can be generated by addressing factor weighting integration with the initial scale a_c^G, as in the equation below:

$$ma_{ef}^{G} = \bar{a}_{cd} \times a_c = [\bar{a}_{cd}^{G}]_{e\times g} \times [a_c^{G}]_{g\times f} = [aa_{mn}^{G}]_{ef} \tag{11}$$

where aa_{mn} can be denoted as $[aa_{mn}^{1G}, aa_{mn}^{2G}, aa_{mn}^{3G}, aa_{mn}^{4G}, aa_{mn}^{5G}]$.

Next, the value of the corresponding membership function can be obtained using the following equation:

$$mfa_{ef}^{G} = 1 \times aa_{mn}^{1G} + 2 \times aa_{mn}^{2G} + 3 \times aa_{mn}^{3G} + 4 \times aa_{mn}^{4G} + 5 \times aa_{mn}^{5G} \tag{12}$$

Accordingly, the overall weighting ova_{xy}^{G} under the goal can be acquired using the following equation:

$$ova_{ef}^{G} = \frac{mfa_{ef}^{G}}{\sum_{e=1}^{m} mfa_{ef}^{G}}, \quad f = 1,2, \ldots, n \tag{13}$$

Arranging these overall weightings acquires the unweighted supermatrix $A = [ova_{ef}^{G}]_{n\times n}$. Then, the entropy weights must be considered in the unweighted supermatrix for transference into the weighted matrix A through the following equation:

$$A = A \times B_t^e = [ova_{ef}^{G}\beta_t^e]_{n\times n} \tag{14}$$

In addition, the supermatrix should be column stochastic (the sum of the column must be equal to 1), or the decision maker must provide the weights to ensure that the column is stochastic. Finally, the supermatrix A must adopt the following equation to acquire accurate relative weights by applying the stepwise convergence of the interdependent relationship:

$$A = \lim_{e\to\infty} A' \tag{15}$$

3.3. Proposed analytical procedures

Step 1: Finalizing the proposed aspect and criteria with experts

This study selected 7 aspects and 27 criteria through a comprehensive literature review. Then, these attributes were presented to an expert group to confirm their reliability and validity. The expert group consisted of 5 professors, 3 firm presidents, 17 senior managers and 10 senior engineers who had more than seven years of working experience in the related industry. These experts responded to the questionnaire based on their professional knowledge and personal experience.

Step 2: Acquiring the social media data

To consider qualitative information in the decision-making process, this study selected three well-known Chinese electronic firms (Huawei Technologies Co., Ltd., China Telecom Corporation and Lenovo Group Ltd.) to acquire social media data by utilizing a web crawler. Subsequently, these acquired frequencies adopted Eqs. (1)–(3) for transformation into entropy weights for further calculations.

Step 3: Aggregating experts' opinions

The experts' opinions were aggregated and used to develop the comparison matrix. The assessments are displayed by linguistic preference and were transferred into the fuzzy synthetic scale in Table 3. Eqs. (4)–(9) were applied to acquire the MC and CR to check the correlation and consistency of each comparison matrix.

Step 4: Obtaining the over weightages for unweighted supermatrix

This individual comparison matrix integrated factor weightings and initial scale to obtain the membership function through Eqs. (10)–(12). Then, Eq. (13) was applied to generate the overall weightings to arrange the unweighted supermatrix.

Table 5
Overall Weightings among Goal, Aspects and Criteria.

	Goal				A1				A2	
	Value	Sum	Factor Weight	Group Weight	Value	Sum	Factor Weight	Group Weight	Value	Sum
C1	2.943		0.237		3.171		0.269		2.971	
C2	3.086	12.429	0.248	0.151	2.886	11.800	0.245	0.146	3.600	12.657
C3	3.000		0.241		2.800		0.237		3.029	
C4	3.400		0.274		2.943		0.249		3.057	
C5	2.857		0.231		2.971		0.242		2.571	
C6	3.029	12.371	0.245	0.150	3.000	12.257	0.245	0.151	3.200	11.886
C7	3.057		0.247		3.114		0.254		3.200	
C8	3.429		0.277		3.171		0.259		2.914	
C9	2.800		0.236		2.657		0.241		3.400	
C10	2.857	11.857	0.241	0.144	2.343	11.029	0.212	0.136	2.914	12.457
C11	3.200		0.270		3.114		0.282		3.257	
C12	3.000		0.253		2.914		0.264		2.886	
C13	2.943		0.236		3.114		0.257		3.000	
C14	3.114	12.457	0.250	0.151	3.114	12.114	0.257	0.150	3.286	12.486
C15	3.257		0.261		3.000		0.248		3.029	
C16	3.143		0.252		2.886		0.238		3.171	
C17	3.029		0.240		3.543		0.284		2.971	
C18	3.000	12.629	0.238	0.153	2.543	12.457	0.204	0.154	2.800	11.514
C19	3.029		0.240		3.114		0.250		2.886	
C20	3.571		0.283		3.257		0.261		2.857	
C21	3.029		0.363		2.943		0.314		2.914	
C22	2.714	8.343	0.325	0.101	3.229	9.371	0.345	0.116	3.457	8.943
C23	2.600		0.312		3.200		0.341		2.571	
C24	2.914		0.239		2.971		0.248		2.914	
C25	3.114	12.200	0.255	0.148	3.114	12.000	0.260	0.148	2.886	11.714
C26	3.286		0.269		2.886		0.240		2.886	
C27	2.886		0.237		3.029		0.252		3.029	

	A2		A3				A4				A5
	Factor Weight	Group Weight	Value	Sum	Factor Weight	Group Weight	Value	Sum	Factor Weight	Group Weight	Value
C1	0.235		2.429		0.200		3.114		0.257		3.286
C2	0.284	0.155	3.514	12.171	0.289	0.150	2.829	12.114	0.233	0.150	2.600
C3	0.239		3.343		0.275		3.086		0.255		2.943
C4	0.242		2.886		0.237		3.086		0.255		3.229
C5	0.216		3.086		0.251		2.829		0.241		3.057
C6	0.269	0.146	2.857	12.314	0.232	0.151	3.057	11.714	0.261	0.145	2.971
C7	0.269		3.286		0.267		2.686		0.229		3.171
C8	0.245		3.086		0.251		3.143		0.268		3.543
C9	0.273		2.857		0.230		2.686		0.218		2.914
C10	0.234	0.153	2.914	12.400	0.235	0.152	3.229	12.343	0.262	0.153	3.257
C11	0.261		3.600		0.290		3.314		0.269		3.000
C12	0.232		3.029		0.244		3.114		0.252		2.914
C13	0.240		2.943		0.256		3.086		0.257		3.057
C14	0.263	0.153	2.743	11.514	0.238	0.142	3.114	12.000	0.260	0.149	3.086
C15	0.243		3.057		0.266		2.943		0.245		2.743
C16	0.254		2.771		0.241		2.857		0.238		3.057
C17	0.258		2.829		0.238		2.829		0.237		3.000
C18	0.243	0.141	2.914	11.886	0.245	0.146	2.857	11.914	0.240	0.147	3.257
C19	0.251		2.971		0.250		3.000		0.252		2.971

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Table 5 (*continued*)

	A2		A3				A4				A5
	Factor Weight	Group Weight	Value	Sum	Factor Weight	Group Weight	Value	Sum	Factor Weight	Group Weight	Value
C20	0.248		3.171		0.200		3.229		0.271		2.914
C21	0.326		3.343		0.289		3.143		0.353		3.286
C22	0.387	0.110	2.857	8.886	0.275	0.109	2.714	8.914	0.304	0.110	2.971
C23	0.288		2.686		0.237		3.057		0.343		2.943
C24	0.249		3.171		0.251		3.086		0.262		2.886
C25	0.246	0.143	3.171	12.200	0.232	0.150	2.629	11.800	0.223	0.146	3.057
C26	0.246		3.143		0.267		3.257		0.276		3.029
C27	0.259		2.714		0.251		2.829		0.240		2.886

	A5			A6				A7			
	Sum	Factor Weight	Group Weight	Value	Sum	Factor Weight	Group Weight	Value	Sum	Factor Weight	Group Weight
C1		0.273		2.771		0.228		2.914		0.234	
C2	12.057	0.216	0.147	3.457	12.171	0.284	0.149	3.200	12.457	0.257	0.150
C3		0.244		3.000		0.246		3.371		0.271	
C4		0.268		2.943		0.242		2.971		0.239	
C5		0.240		2.800		0.233		2.714		0.227	
C6	12.743	0.233	0.155	3.057	12.000	0.255	0.147	3.229	11.971	0.270	0.144
C7		0.249		3.257		0.271		3.057		0.255	
C8		0.278		2.886		0.240		2.971		0.248	
C9		0.241		3.114		0.263		2.714		0.214	
C10	12.086	0.270	0.147	2.429	11.857	0.205	0.146	3.486	12.657	0.275	0.152
C11		0.248		3.057		0.258		3.314		0.262	
C12		0.241		3.257		0.275		3.143		0.248	
C13		0.256		3.200		0.262		2.943		0.244	
C14	11.943	0.258	0.146	3.171	12.229	0.259	0.150	2.971	12.057	0.246	0.145
C15		0.230		2.914		0.238		3.143		0.261	
C16		0.256		2.943		0.241		3.000		0.249	
C17		0.247		3.229		0.280		3.343		0.255	
C18	12.143	0.268	0.148	2.686	11.543	0.233	0.142	3.286	13.114	0.251	0.157
C19		0.245		2.800		0.243		3.257		0.248	
C20		0.240		2.829		0.245		3.229		0.246	
C21		0.357		3.000		0.303		3.029		0.329	
C22	9.200	0.323	0.112	3.171	9.914	0.320	0.122	3.314	9.200	0.360	0.110
C23		0.320		3.743		0.378		2.857		0.311	
C24		0.243		2.714		0.231		2.829		0.239	
C25	11.857	0.258	0.145	3.143	11.743	0.268	0.144	3.257	11.829	0.275	0.142
C26		0.255		2.914		0.248		2.543		0.215	
C27		0.243		2.971		0.253		3.200		0.271	

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Table 6
Unweighted Supermatrix.

	Goal	A1	A2	A3	A4	A5	A6	A7	C1	C2	C3
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A1	0.143	0.131	0.151	0.133	0.142	0.147	0.147	0.129	0.000	0.000	0.000
A2	0.136	0.136	0.127	0.134	0.158	0.144	0.149	0.153	0.000	0.000	0.000
A3	0.136	0.160	0.141	0.134	0.130	0.142	0.135	0.135	0.000	0.000	0.000
A4	0.167	0.156	0.146	0.120	0.154	0.134	0.131	0.138	0.000	0.000	0.000
A5	0.132	0.142	0.133	0.154	0.154	0.137	0.149	0.152	0.000	0.000	0.000
A6	0.138	0.136	0.142	0.169	0.127	0.142	0.136	0.148	0.000	0.000	0.000
A7	0.147	0.138	0.161	0.154	0.136	0.155	0.153	0.145	0.000	0.000	0.000
C1	0.036	0.039	0.036	0.030	0.039	0.040	0.034	0.035	0.037	0.038	0.039
C2	0.038	0.036	0.044	0.043	0.035	0.032	0.042	0.038	0.037	0.030	0.038
C3	0.036	0.035	0.037	0.041	0.038	0.036	0.037	0.040	0.037	0.041	0.037
C4	0.041	0.036	0.037	0.035	0.038	0.039	0.036	0.036	0.038	0.041	0.042
C5	0.035	0.037	0.031	0.038	0.035	0.037	0.034	0.033	0.037	0.036	0.036
C6	0.037	0.037	0.039	0.035	0.038	0.036	0.038	0.039	0.034	0.033	0.036
C7	0.037	0.038	0.039	0.040	0.033	0.039	0.040	0.037	0.036	0.041	0.042
C8	0.042	0.039	0.036	0.038	0.039	0.043	0.035	0.036	0.037	0.038	0.036
C9	0.034	0.033	0.042	0.035	0.033	0.036	0.038	0.033	0.039	0.036	0.035
C10	0.035	0.029	0.036	0.036	0.040	0.040	0.030	0.042	0.038	0.036	0.034
C11	0.039	0.038	0.040	0.044	0.041	0.037	0.038	0.040	0.035	0.041	0.039
C12	0.036	0.036	0.035	0.037	0.039	0.036	0.040	0.038	0.034	0.033	0.037
C13	0.036	0.038	0.037	0.036	0.038	0.037	0.039	0.035	0.039	0.033	0.034
C14	0.038	0.038	0.040	0.034	0.039	0.038	0.039	0.036	0.036	0.042	0.034
C15	0.040	0.037	0.037	0.038	0.036	0.033	0.036	0.038	0.032	0.037	0.033
C16	0.038	0.036	0.039	0.034	0.035	0.037	0.036	0.036	0.040	0.033	0.037
C17	0.037	0.044	0.036	0.035	0.035	0.037	0.040	0.040	0.033	0.037	0.036
C18	0.036	0.031	0.034	0.036	0.035	0.040	0.033	0.039	0.037	0.033	0.038
C19	0.037	0.038	0.035	0.037	0.037	0.036	0.034	0.039	0.038	0.036	0.038
C20	0.043	0.040	0.035	0.039	0.040	0.036	0.035	0.039	0.038	0.041	0.041
C21	0.037	0.036	0.036	0.041	0.039	0.040	0.037	0.036	0.037	0.041	0.037
C22	0.033	0.040	0.042	0.035	0.034	0.036	0.039	0.040	0.039	0.043	0.038
C23	0.032	0.039	0.031	0.033	0.038	0.036	0.046	0.034	0.035	0.039	0.036
C24	0.035	0.037	0.036	0.039	0.038	0.035	0.033	0.034	0.037	0.036	0.034
C25	0.038	0.038	0.035	0.039	0.033	0.037	0.039	0.039	0.039	0.034	0.042
C26	0.040	0.036	0.035	0.039	0.040	0.037	0.036	0.031	0.043	0.038	0.036
C27	0.035	0.037	0.037	0.033	0.035	0.035	0.036	0.038	0.037	0.034	0.035

	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C1	0.036	0.041	0.035	0.042	0.035	0.038	0.034	0.043	0.037	0.038	0.047	0.030
C2	0.040	0.032	0.043	0.036	0.038	0.034	0.039	0.034	0.040	0.040	0.037	0.037
C3	0.034	0.040	0.035	0.034	0.037	0.033	0.029	0.038	0.036	0.034	0.040	0.039
C4	0.037	0.035	0.036	0.037	0.031	0.037	0.039	0.034	0.037	0.040	0.035	0.038
C5	0.038	0.037	0.043	0.033	0.033	0.040	0.035	0.038	0.045	0.034	0.036	0.036
C6	0.032	0.034	0.038	0.034	0.038	0.038	0.037	0.037	0.036	0.034	0.034	0.034
C7	0.036	0.035	0.033	0.036	0.034	0.037	0.045	0.037	0.043	0.035	0.035	0.036

(continued on next page)

Table 6 (*continued*)

	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C8	0.039	0.034	0.033	0.041	0.039	0.041	0.036	0.036	0.033	0.038	0.042	0.038
C9	0.038	0.038	0.040	0.032	0.036	0.033	0.036	0.035	0.034	0.034	0.042	0.038
C10	0.032	0.037	0.042	0.034	0.037	0.037	0.036	0.035	0.037	0.038	0.038	0.032
C11	0.037	0.037	0.032	0.037	0.039	0.039	0.038	0.041	0.042	0.033	0.039	0.034
C12	0.035	0.036	0.039	0.039	0.037	0.033	0.041	0.033	0.034	0.037	0.035	0.040
C13	0.035	0.034	0.036	0.037	0.037	0.038	0.039	0.036	0.036	0.037	0.038	0.045
C14	0.036	0.043	0.034	0.039	0.037	0.032	0.035	0.042	0.040	0.042	0.037	0.034
C15	0.041	0.034	0.034	0.039	0.044	0.037	0.038	0.037	0.038	0.036	0.035	0.042
C16	0.042	0.037	0.039	0.032	0.037	0.044	0.034	0.039	0.032	0.036	0.038	0.038
C17	0.039	0.040	0.035	0.036	0.032	0.034	0.039	0.035	0.039	0.032	0.037	0.037
C18	0.042	0.040	0.039	0.042	0.034	0.033	0.031	0.039	0.036	0.037	0.036	0.040
C19	0.037	0.039	0.035	0.038	0.037	0.036	0.042	0.038	0.036	0.033	0.032	0.035
C20	0.035	0.035	0.039	0.037	0.037	0.040	0.040	0.038	0.037	0.041	0.034	0.036
C21	0.038	0.036	0.039	0.037	0.033	0.039	0.040	0.035	0.033	0.038	0.033	0.033
C22	0.040	0.034	0.034	0.036	0.044	0.038	0.041	0.039	0.039	0.038	0.031	0.036
C23	0.035	0.039	0.041	0.040	0.039	0.036	0.037	0.034	0.033	0.037	0.037	0.037
C24	0.037	0.038	0.034	0.033	0.041	0.037	0.040	0.035	0.035	0.038	0.039	0.042
C25	0.036	0.041	0.039	0.042	0.041	0.035	0.035	0.040	0.040	0.043	0.038	0.038
C26	0.034	0.042	0.035	0.039	0.040	0.043	0.036	0.034	0.039	0.038	0.036	0.038
C27	0.040	0.031	0.039	0.037	0.035	0.036	0.029	0.037	0.032	0.037	0.038	0.038

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C1	0.033	0.038	0.041	0.039	0.039	0.040	0.037	0.034	0.034	0.035	0.036	0.035
C2	0.038	0.034	0.036	0.036	0.035	0.039	0.043	0.039	0.033	0.038	0.036	0.036
C3	0.039	0.037	0.035	0.036	0.037	0.034	0.037	0.031	0.041	0.039	0.034	0.037
C4	0.038	0.040	0.036	0.038	0.037	0.038	0.038	0.035	0.038	0.030	0.037	0.040
C5	0.035	0.037	0.036	0.039	0.039	0.039	0.034	0.039	0.034	0.034	0.038	0.037
C6	0.040	0.036	0.038	0.033	0.037	0.037	0.041	0.037	0.039	0.040	0.045	0.038
C7	0.038	0.036	0.037	0.034	0.035	0.039	0.041	0.037	0.035	0.038	0.036	0.039
C8	0.037	0.035	0.034	0.033	0.033	0.038	0.038	0.031	0.037	0.033	0.034	0.036
C9	0.039	0.034	0.035	0.036	0.035	0.038	0.038	0.036	0.038	0.040	0.036	0.043
C10	0.038	0.041	0.041	0.031	0.035	0.035	0.036	0.042	0.037	0.038	0.036	0.043
C11	0.036	0.038	0.031	0.040	0.037	0.033	0.030	0.035	0.034	0.041	0.034	0.034
C12	0.038	0.034	0.036	0.034	0.038	0.034	0.037	0.038	0.035	0.039	0.040	0.034
C13	0.039	0.040	0.031	0.039	0.035	0.036	0.034	0.037	0.036	0.039	0.037	0.034
C14	0.034	0.039	0.036	0.036	0.038	0.038	0.029	0.037	0.035	0.035	0.039	0.034
C15	0.038	0.034	0.038	0.036	0.033	0.036	0.037	0.040	0.043	0.037	0.039	0.033
C16	0.038	0.037	0.039	0.041	0.041	0.038	0.039	0.039	0.039	0.036	0.039	0.038
C17	0.038	0.037	0.040	0.037	0.037	0.036	0.037	0.036	0.031	0.040	0.040	0.035
C18	0.036	0.041	0.035	0.037	0.037	0.036	0.042	0.038	0.038	0.039	0.036	0.038
C19	0.038	0.038	0.039	0.039	0.038	0.038	0.039	0.040	0.035	0.037	0.032	0.038
C20	0.039	0.035	0.038	0.038	0.034	0.039	0.035	0.038	0.042	0.038	0.037	0.036
C21	0.034	0.036	0.041	0.037	0.042	0.035	0.034	0.043	0.036	0.030	0.038	0.035
C22	0.036	0.036	0.036	0.039	0.040	0.039	0.038	0.035	0.042	0.038	0.036	0.035
C23	0.037	0.041	0.038	0.039	0.036	0.035	0.041	0.036	0.038	0.045	0.037	0.041

(*continued on next page*)

Table 6 (*continued*)

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27
C24	0.037	0.036	0.038	0.040	0.036	0.034	0.036	0.033	0.040	0.033	0.033	0.037
C25	0.031	0.038	0.039	0.040	0.040	0.035	0.036	0.040	0.037	0.040	0.034	0.037
C26	0.036	0.039	0.038	0.037	0.039	0.041	0.032	0.031	0.035	0.034	0.041	0.041
C27	0.039	0.034	0.037	0.037	0.038	0.040	0.038	0.040	0.037	0.036	0.039	0.039

Step 5: Generating the converged supermatrix and ranks

Once the unweighted supermatrix was obtained, Eq. (14) was used to consider the entropy weights in the decision-making matrix to transform the unweighted supermatrix into a weighted supermatrix. Eventually, Eq. (15) allowed the weighted supermatrix to obtain accurate relative weights.

4. Results

4.1. Case information

The electronics industry in China has the highest production and greatest value of any electronics industry in the world. Huawei Technologies Co., Ltd., China Telecommunications Corporation, and Lenovo Group Ltd. are well-known Chinese electronic firms listed in the Fortune 500 as benchmark firms. Huawei is a multinational networking, telecommunications equipment and services firm and is the largest telecommunications equipment manufacturer in the world. China Telecommunications Corporation is a Chinese state-owned telecommunications firm with the largest fixed-line service in China and is also one of the three largest mobile telecommunications providers in China. Lenovo Group Ltd. is a Chinese multinational technology firm that designs, develops, manufactures and sells personal and tablet computers, smartphones, workstations, servers, electronic storage devices, IT management software and smart televisions.

Although these three benchmark firms have their own KM systems, they lack a hierarchical framework for improving their CSP. Moreover, CSP possesses multidimensional features that require an appropriate approach to big data to increase the accuracy of decision making. To fill these gaps, this study adopts FSM to apply the experts' assessments and promote consistency and utilizes web crawlers to calculate the frequencies of social media and transfer them into entropy weights. Finally, all the data are aggregated into an unweighted supermatrix of ANP to structure a hierarchical ranking framework. The ranking offers a specific direction for firms with limited resources to effectively improve their performance.

4.2. Analytical results

Step 1: Acquiring the social media data and aggregating the assessments

Table 2 shows the accumulating frequencies of these firms by applying the web crawler based on the proposed aspects. These accumulating frequencies must be transferred into entropy weights by employing Eqs. (1)–(3). For example, the integrating entropy weight of economy from these three firms is calculated as $(1-0.129)/[(1-0.129)+(1-0.168)+(1-0.183)+(1-0.084)$ $+(1-0.100)+(1-0.169)+(1-0.178)=0.143]$ (as the number marked in boldface). In addition, the experts are required to assess these seven aspects in relation to the goal, as shown in Table 3.

Step 2: Obtaining the membership function, crisp values and MC

The assessments must adopt Eqs. (4)–(6) to obtain the membership function and crisp value, as presented in Table 4. The crisp value of C1 under the goal is computed by $\times 0.200+2\times 0.143+3\times 0.229+4\times 0.143+5\times 0.286=3.171$ as the number marked in gray, which represents the defuzzification result of the experts' assessment of C1 under the goal. Then, Eq. (7) is applied to generate MC and create the ranking.

Step 3: Checking the consistency of assessments

Eq. (8) is applied to acquire the C.I.; then, $\lambda_{\max}=1$ is obtained by

Table 7
Converged Supermatrix.

	Goal	A1	A2	A3	A4	A5	A6	A7	C1	C2	C3
Goal	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382
A1	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
A2	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
A3	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
A4	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
A5	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
A6	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
A7	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
C1	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C2	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C3	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C4	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C5	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C6	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C7	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C8	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C9	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C10	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C11	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C12	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C13	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C14	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C15	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C16	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C17	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C18	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C19	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C20	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
C21	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C22	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C23	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
C24	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C25	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C26	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C27	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015

	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Goal	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382
A1	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
A2	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
A3	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
A4	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
A5	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
A6	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
A7	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
C1	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C2	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C3	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C4	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C5	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C6	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C7	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015

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Table 7 (*continued*)

	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C8	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C9	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C10	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C11	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C12	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C13	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C14	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C15	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C16	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C17	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C18	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C19	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C20	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
C21	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C22	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C23	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
C24	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C25	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C26	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
C27	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	Rank
Goal	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382	1
A1	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	4
A2	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	6
A3	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	7
A4	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	2
A5	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	8
A6	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	5
A7	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	3
C1	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	25
C2	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	18
C3	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	26
C4	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	10
C5	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	32
C6	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	23
C7	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	19
C8	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	11
C9	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	34
C10	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	31
C11	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	16
C12	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	27
C13	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	28
C14	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	17
C15	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	13
C16	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	15
C17	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	24
C18	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	21
C19	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	20
C20	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	9
C21	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	22
C22	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	33
C23	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	35

(*continued on next page*)

Table 7 (*continued*)

	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	Rank
C24	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	29
C25	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	14
C26	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	12
C27	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	30

adopting MATLAB and inserting it into the equation C.I. = (1 − 1)/(7 − 1) = 0. Subsequently, Eq. (9) generates the *CR* as 0/1.36 = 0, which is less than 0.1, indicating that the assessments of the expert group possess high consistency; otherwise, the experts would be asked to complete the questionnaire again.

Step 4: Generating the unweighted supermatrix

All the weightings of aspects and goals are attained by utilizing Eq. (10) based on the arrangement of the proposed aspects. Then, Eqs. (11)–(13) are applied to obtain the overall weightings, as shown in Table 4. These overall weightings must be arranged into the unweighted supermatrix through Fig. 1 and Eq. (14), as shown in Table 5.

Step 5: Obtaining the converged supermatrix and ranks

Finally, the unweighted supermatrix must implement Eq. (15) to acquire the converged supermatrix A, as shown in Table 6. The top consideration is the goal, followed by A4, A7 and A1. In addition, the ranking of the criteria is compared with the MC ranking under the goal, confirming that the top three criteria are C20, C8 and C4 (as shown in Table 7).

5. Implications

5.1. Theoretical implications

A few studies have developed a hierarchical model of interrelationships for CSP (Tseng et al., 2018) and have taken the KM into account. However, a gap remains with regard to guiding electronic firms to improve their CSP. The results of this study not only simplify the complicated interrelationships in the hierarchical framework but also provide support for bridging KM and CSP by taking social media data into account. The analytical results show that for Chinese electronic firms that want to significantly improve CSP, the aspects of relation (A4), operation (A7) and economy (A1) must align with the goal priority.

Relation refers to maintaining the steady development of interest chains for firms. This aspect emphasizes that co-benefits can be achieved only by establishing a rigid relation in improving CSP (Wu et al., 2018). The rigid relation must be established by developing external collaboration (C15). External collaboration enables the expansion of or addition to the values of the currently practiced KM. Without external collaboration, KM may exhaust the internal resources of Chinese electronic firms and depress their CSP. In addition, external collaboration involves the way stakeholders engage with KM to achieve common interests. KM generates great value added and leads to significant improvements of CSP if the developing external collaboration involves all related stakeholders.

In addition, the findings support the argument that previous studies concentrated excessively on discussing CSP from the perspective of the triple bottom line (Tseng, 2017; Shi et al., 2017; Tseng et al., 2018). Operation (A7) is still absent from the current literature that addresses the practice of sustainable development (Wu et al., 2016). Accordingly, KM assists Chinese electronic firms in making improvements by adopting IT-supported processes (C26). These processes enable the integration, spread, development and utilization of knowledge with greater efficiency and effectiveness in managing resource consumption and production to enhance CSP and provide digital information to support decision making. In particular, Chinese electronic firms must take social media data into account to satisfy customers' needs and enhance the accuracy of their decision making.

Despite previous studies that argued that social and environmental aspects might decrease economic performance (Tseng et al., 2015; Tseng et al., 2018), the aspect of economy (A1) still plays an important role in CSP. Therefore, expanding capital for developing KM (C4) not only generates economic sustainability to promote CSP but also assists Chinese electronic firms from different perspectives in building competitive advantages to promote economic growth. Without expanding capital to develop KM, Chinese electronic firms might waste time in trial and error searches for effective improvements, which would cause a decrease in CSP.

5.2. Managerial implications

Expanding capital to develop KM (C4) implies that Chinese electronic firms should spend additional funds to seek efficient ways to manage knowledge. Although several Chinese firms have attempted to generate this expansion in the short term by improving their economic performance, they ignore the advantages of additional funding that can generate long-term conservation, while KM enables the improvement of the accuracy of decision making. The benchmark firms have established special departments and recruited employees for this expansion to enable knowledge mining, acquisition, storage, processing, analysis and application because they believe that KM can enhance CSP once valuable information has been obtained.

Because KM contains diverse features and burgeoning data, it relies on the adoption of IT-supported processes (C26) to gather the data for each process on time. Chinese electronic firms also adopt the big data approach to create critical consumption systems for improving CSP. For example, Huawei launched IT-supported processes and utilized big data analysis to propose 36 items for improvement and then applied 22 items to achieve annual energy savings of 4.62 million kWh and reduce carbon emissions by 4008 tons in 2017. Furthermore, IT-supported processes can monitor whether the entire CSP process follows the appropriate standards. These collected data enable managers to immediately support decision making and effectively address emerging situations as they occur.

Developing external collaboration (C15) depends on these electronic firms' exploration of approaches to external cooperation in terms of new modes of collaboration, deepening the scope of cooperation, expanding the collaboration space, and strengthening strategic collaboration at the levels of product research and development, market development, and resource and capital sharing and management. Attaining co-benefits requires firms to create open platforms, and channels for cooperation and co-projects should be properly designed and implemented (Wu et al., 2018). For example, Lenovo searched for suppliers from hub zone areas and expanded the shareholding of disabled military members, disadvantaged minorities, people with disabilities, women, minorities, lesbian, gay, bisexual and transgender people, veterans, and small and medium enterprises to develop external collaboration under CSP considerations.

In summary, electronic firms are striving to improve their CSP without precise guidelines. Nevertheless, the results indicate that expanding capital for developing KM, adopting IT-supported processes and developing external collaboration enables firms to achieve better performance in managing the knowledge. Huawei and Lenovo provide benchmarking practices for guiding electronic firms to improve CSP by rearranging their KM.

6. Conclusions

The electronic industry not only strives to improve human life but also seeks efficient and effective ways to improve CSP. However, large amounts of digital knowledge that is stored in servers might be ignored when exploring such improvements. Only a few studies have attempted to bridge CSP and KM and have considered the interrelationship between these two themes (Inkinen et al., 2015). Furthermore, previous studies have concentrated on economic, environmental and social aspects in addressing the issues of CSP, and these aspects are insufficient for a comprehensive consideration. To address these issues, diverse information must be taken into account to enhance accuracy. This study adopts a hybrid method to structure a hierarchical framework of CSP from the practices of KM.

This study presents three contributions. (1) It provides a theoretical contribution by bridging KM and CSP with extensive consideration of the economic, environmental, societal, relational, resilience, long-term and operations aspects. This bridging offers a way for electronic firms to improve CSP efficiently and effectively. (2) It makes a methodological contribution by considering the interrelationship among the proposed aspects and criteria to reflect the real situation and promote the validity and reliability of the framework by adopting web crawler-gathered information from official websites and transferring this information into entropy weights and then integrating with FSM-ANP to develop the hierarchical framework. The proposed hybrid method enables the enhancement of the accuracy of decision making by taking diverse data into account. (3) This study develops a framework to provide a precise direction to lead electronic firms in making improvements given resource constraints.

The findings reveal that the proposed seven aspects can provide a more comprehensive consideration of CSP than previous studies. The top three aspects of relations, operations and the economy must align with the goal of achieving better performance. Thus, Chinese electronic firms that want to improve their relations with stakeholders must first launch the practice of developing external collaboration. External collaboration enables firms to push the limitations and boundaries of internal resources. This study also suggests that electronic firms adopt IT-supported processes to support decision makers in monitoring resource consumption and production to promote operations efficiently and effectively by integrating, spreading, developing and utilizing knowledge to ensure the performance of CSP. The results indicate that expanding capital for developing KM plays an important role in improving economic performance. This expanding capital can be conducted into knowledge mining, acquisition, storage, processing, analysis and application to obtain valuable information for improving CSP.

This study has several limitations that require further research. Although the proposed seven aspects have been verified, future studies should consider as many more aspects as possible to create a comprehensive discussion of CSP. In addition, this study focuses on the Chinese electronic industry; therefore, the results may not be generalizable. Future studies should use the proposed analytical procedures to investigate different countries and industries and make comparisons. The proposed hybrid method is designed to solve this problem, and further studies are needed to analyze the sensitivity of the proposed hybrid method compared to other methods. The main feature of the multi-criteria decision-making method is that the questionnaire contains a large number of items, which reduces the consistency and patience of the experts who make the assessments. Further study is required to improve this critical issue and enhance consistency.

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Appendix A

Appendix 1: Corresponding Fuzzy Synthetic Scale

Linguistic Preference	Corresponding Fuzzy Synthetic Scales
Very low (VL)	1
Low (L)	2
Medium (M)	3
High (H)	4
Very high (VH)	5

Appendix 2: Average Random Consistency Index

Level(s)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

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