Modelling cross-border supply chain collaboration: The case of the Belt and Road Initiative

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Abstract

The Belt and Road Initiative (BRI) has resulted in international, cross-border supply chains returning to a new prominence. The BRI presents opportunities for cross-border supply chain collaboration research. Assessing the influencing factors of cross-border supply chain collaboration is beneficial for understanding and improving this evolving, globally influential international trade policy. The BRI is quite complex so that subjective assessment methods are useful but should be improved. To address this issue, this paper initially develops a cross-border supply chain collaboration factor framework based on synergetic theory. A vague set and DEMATEL methods are integrated to form a unified model to support the assessment. A combination weighting that uses analytical hierarchy process (AHP) and an entropy weighting method, i.e., a data crawler for BRI-related documents, to ensure that objective importance weights of the factors in the Belt and Road context are achieved. The results show that information sharing, profit allotment, the degree of trust and goal congruence as common drivers of supply chain collaboration are not driving factors in the Belt and Road cross-border context. They are core issues that do not affect cross-border supply chain collaboration directly. Senior manager support and customs regulation are two important drivers of cross-border supply chain collaboration. The practitioners of cross-border supply chain collaboration should not only focus on the support from senior managers and customs regulation but also attempt to improve performance, such as information sharing and trust, to obtain more support from senior managers and policy makers to promote cross-border supply chain collaboration indirectly.

Keywords: cross-border; supply chain collaboration; “the Belt and Road”; combination weighting; vague DEMATEL

1 Introduction

Increasing global competition and world economic integration have shifted competition from between individual firms to between supply chains (Christopher, 1992). Supply chain collaboration (SCC) and integration has also increased in importance (Autry, 2013). This collaboration and integration have expanded to global relationships. Some global supply chain relationships have become part of national policies. China recently released the “Vision and action to promote the construction of the Silk Road Economic Belt and the maritime Silk Road twenty-first Century”, i.e., the “the Belt and Road” initiative (BRI). Given this Chinese globalization policy, Chinese firms are increasingly seeking to realize cross-border SCC. The initiative not only encourages cross-border trade but also emphasizes cross-border cooperation (Zhang, 2017). Research on cross-border SCC in the BRI context can help provide a greater understanding of this emergent global economic environment.

Analysing the factors that influence cross-border SCC, namely, the antecedent factors, can aid the clarification of the prospects for organizational supply chain management in this context. This research addresses this aspect and evaluates it along two different aspect dimensions. One dimension is SCC. Many studies on SCC seek to determine the factors that influence SCC performance. Factors may include information sharing (Li et al., 2014), trust mechanisms (Ha et al., 2011) and information technology (Wang et al., 2014; Wu and Chiu, 2018). The second dimension is cross-border-globalized and international supply chains. Such studies include cross-border e-commerce (Chen and Yang, 2017) and cross-border logistics networks (Shi and Liu, 2012). Few studies emphasize the antecedent factors for cross-border SCC, especially in the context of the BRI. There is no current assessment criteria framework that can be directly adopted for this study. Given the evolving international trade and socio-political landscape, the criteria for assessing cross-border SCC may require reconsideration and new development. In order to enable firms involved in cross-border SCC to benefit from the BRI as an evolving globalization initiative, a new scientific assessment framework of influencing factors for cross-border SCC is proposed.

Numerous research assessment methods exist for evaluating the relationships of multiple supply chain management factors. The methods include the technique for order preference by similarity to ideal solution (TOPSIS) (Zhao et al., 2017; Tseng et al., 2018), analytic hierarchy process (AHP) (Prasannavenkatesan and Goh, 2016; Luthra et al., 2016; Sedighi, 2017), data envelopment analysis (DEA) (Wu et al., 2016; Seufert et al, 2017), an interpretative structural model (ISM) (Cui et al., 2018a), and decision making and trial evaluation laboratory (DEMATEL) (Wu et al., 2015; Ha et al., 2017; Cui et al., 2018b). Among them, the DEMATEL method can effectively analyse the causal relationships among system factors with the capability of determining the strength of these relationships (Gandhi et al., 2015; Li and Mathiyazhagan, 2018). This analysis characteristic is conducive to identifying the driving factors along with the core concerns that affect cross-border SCC. Traditional DEMATEL cannot overcome the problem of expert semantic ambiguity (Abdullah and Zulkifli, 2018); grey theory, fuzzy sets and rough sets are usually introduced into DEMATEL to address this limitation (Wu et al., 2017; Bai et al., 2018). Some studies also indicate that factor weights may be subjective and unreasonable (Cao and Ling, 2002). With vague DEMATEL, we propose a combination weighting approach to assess the influencing factors of cross-border SCC.

The purpose of this study is to assess the influencing factors for cross-border SCC in the BRI context. The contributions of this study include (1) developing an assessment framework of cross-border SCC through a synergetic theoretic lens (Haken, 1973). Specifically, we identify the criteria for cross-border SCC through intra-subsystems, inter-subsystems and external systems dimensions.

(2) We also propose an assessment method based on combination weighting, which furthers assessment objectivity and accuracy. To overcome expert semantic ambiguity, vague DEMATEL is used as the main assessment method. To influence factor weighting, we combine subjective weights and objective weights. AHP is used for subjective weighting; the official BRI website is evaluated by using content analysis – namely, word frequency statistics – to obtain more objective weights of each factor to further enhance the accuracy of the evaluation result in the BRI context. (3) There are some new findings in this study. In the context of cross-border transactions and the BRI, some factors such as information sharing, and trust do not drive SCC directly but rather indirectly through senior manager support and customs regulation. The corresponding suggestions are also provided. The remainder of this paper is organized as follows. Section 2 is a literature review. The proposed methodology is discussed in Section 3. Section 4 includes an application illustration of the proposed approach and sensitivity analysis. Section 5 elaborates on the theoretical and managerial implications. Finally, the conclusion, research limitations and suggestions for future studies are presented in Section 6.

2. Literature review

2.1 The Belt and Road Initiative

The BRI is an emergent cooperative trade model for Europe and Asia as proposed in September 2013 by President Xi Jinping of China and his administration. “Belt” refers to the economic belt jointly established by countries along the ancient Silk Road for cooperation and development. “Road” refers to the maritime Silk Road developed with other countries of the Association of Southeast Asian Nations (ASEAN). In March 2015, with approval by the State Council, several government departments jointly issued BRI policies (Cheng et al., 2016). The BRI includes 65 countries and regions; it encourages the construction of cross-border cooperative industrial parks, cross-border trade cooperation parks, and other cooperative projects that can include infrastructure development and multiple types of exchanges (Li et al., 2018). Another BRI goal helps promote regional economic cooperation by linking China to Asia, Africa and Europe (Huang, 2016). China's economic and trade exchanges with the countries in the BRI are likely to be multi-tiered. The cross-border commodity and service trade is expected to expand. People, goods and capital flows will be more frequent. The demand for cross-border supply chain and SCC understanding and study will accordingly increase.

The BRI supports cross-border cooperation and the progressive requirements for cross-border supply chain development. Scholars have investigated BRI supply chain issues by conducting various studies. Supply chain cross-border coordination from a business and economic perspective has been a major focus. Cost sharing contracts on key decisions for mass customization logistics services supply chains (Liu et al. 2018), product quality to explore the dynamic behaviour of retailers that obtain the optimal profit (Bao and Ma, 2018), and international logistics network reconstruction under the BRI (Sheu and Kundu, 2018) are examples of SCC. BRI eco-efficiency improvement of agricultural product goals (Zhao et al., 2018) and BRI green supply chain construction are sought to jointly introduce economic and ecological benefits (Fu, 2018). The supporting tools for evaluations in the BRI environment such as decision-making for green supplier selection have also started to emerge (Lin et al. 2017). These additional examples of studies show emergent BRI sustainability concerns.

These studies have focused on cross-border supply chains or logistics. Supply chain partner coordination remains an underexplored and urgent concern (Chen et al., 2017; Wong et al., 2011). Although the BRI supports cross-border trade cooperation, the cooperation between China and BRI country partners is still in its infancy. Problems such as loose cooperation, unsound mechanisms, and insufficient guidance and depth are prominent (Fu et al., 2018). This situation increases the difficulty of cross-border SCC. Some scholars maintain that one of the largest obstacles is distrust from neighbouring countries (Huang, 2016), while other scholars are concerned about legal risks (Li, 2017a). However, a comprehensive exploration of the influencing factors of cross-border SCC with the BRI is still a research gap. There is a necessity to systematically discuss which factors affect cross-border SCC to inform research, policy, and practice.

2.2 Supply chain collaboration

SCC can support effective and efficient supply chain management (Fu and Piplani, 2004). There is no uniform definition of SCC (Holweg et al., 2005). SCC ranges from simple transactions to highly integrated relationships (Goffin et al., 2006), from collaborative communications to supplier development (Oh and Rhee, 2008), and from internal collaboration to external collaboration (Frohlich and Westbrook, 2001). SCC's broad scope, large number of actors involved, and process complexities contribute to the factor diversity of SCC evaluation, including information sharing (Hudnurkar et al., 2014), trust, and technical capabilities (Salam, 2017). In this paper, we adopt a general description of SCC as involving two or more autonomous organizations that form long-term relationships to work closely on planning and executing supply chain operations to achieve common mutually beneficial goals (Mehrjerdi, 2002; Sheu et al., 2006).

The BRI provides an impetus for the greater cross-border trade evaluation of supply chains. Supply chain emphasis increases on cross-regional and cross-national supply chains in the BRI. Compared with traditional domestic supply chains, cross-border supply chains are likely to include more links, greater business complexity, and uncertainties (Zhou, 2016), and cross-border SCC, which focuses on the cross-national trade, faces greater barriers. Some scholars have studied cross-border supply chains from the perspective of cross-border e-commerce. Recent research on logistics coordination investigates different supply chain logistics coordination parameters for cross-border e-commerce (Xiao, 2017). These coordination parameters include the service capability of cross-border logistics functions, the information sharing level, and resource allocation capability.

Additional factors and concerns in various cross-border industries and supply chains have also occurred. The relational learning ability of firms across the supply chain is an important aspect of cross-border supply chain research. This learning ability affects the relationship value between suppliers and buyers (Cheung, 2010). The alliance management of cross-border supply chains requires comprehensively considering the three objectives of profit, collaboration and environmental orientation (van Roekel, 2002). The research in cross-border tourism supply chains shows the impact of commissions, hospitality and administrative costs on cross-border tourism supply chains (Tsaur and Chen, 2018).

In summary, current research focuses on some specific factors, such as learning ability, or some dimensions, such as profit, collaboration and environmental orientation, but without further elaboration. As a result, a comprehensive picture of the influencing factors of cross-border SCC is lacking. A mature criteria system to measure the influencing factors of cross-border SCC, especially within the BRI context, does not exist. This is a major motivation for a new comprehensive system that combines existing approaches in the literature and requires an extension to the BRI context. Identifying and determining the relationships of these factors, both existing and BRI-extended, is still lacking. This gap in the academic research restricts the development of cross-border SCC. Thus, there is a necessity to systematically discuss which factors affect cross-border SCC to inform research, policy, and practice.

2.3 Theoretical foundation and methods

It is often difficult for organizations to put collaboration into practice (Gajda, 2004). Current research shows that SCC has a high failure rate (Jeng, 2015). Cross-border supply chains are ever more complex, which implies greater chances for SCC failure. Studying SCC influencing factors in the BRI context can help a further understanding of SCC, especially in cross-border situations (Birpalia, 2018)

Theory can also help to understand and refine these influencing factors. We use a systems-based synergetic theoretic lens to help determine the factors and their interrelationships. Synergetic theory (Haken, 1973), which evolved from thermodynamic principles, posits that system evolution results from internal and external interactions. The external environment provides the conditions for system evolution that enable the internal system to organically develop to an optimal state. This theory is suitable for studying collaboration activities and has relevance in management. Synergetic theory has been used to study the importance of supply chain integration within a dynamic supply chain integration network model (Wen et al., 2007). Stakeholder and dynamic capability theories have been linked to the management and alignment of internal and external balances posited by synergetic theory (for example, see Morkan et al. 2017 and Teece, 2018). Developing an assessment framework based on synergetic theory can help expand the knowledge on SCC.

An appropriate assessment method supports research accuracy. There are many assessment methods used to investigate similar topics related to antecedent factors. These methods include DEMATEL (Tzeng et al., 2007; Bai et al., 2017), AHP (Luthra et al., 2016), DEA (Wu et al., 2016; Seufert et al., 2017), TOPSIS (Zhao et al., 2017) and ISM (Cui et al., 2018a). However, each method has both advantages and limitations. For example, TOPSIS is used to rank according to the proximity of a limited number of evaluation objects to idealized goals; DEA is mainly used to compare the input-output efficiency of several subjects that provide similar services; and ISM is used to construct a hierarchical structure. However, in our study, we need to explore the relationship between influencing factors and cross-border SCC. Thus, DEMATEL is selected as the main research method in this paper. The DEMATEL method is commonly used to analyse the causal relationships among multiple factors (Mavi and Shahabi, 2015) and develop a systemic influence structure based on the factor relationships (Lee et al., 2008). DEMATEL has been used in a variety of ways, namely, in the causal relationship between various obstacles from the supply chain perspective, such as the re-manufacturing supply chain (Zhu et al., 2015). Extensions to DEMATEL include an integration of fuzzy or grey set methods to solve semantic ambiguities (Xia et al, 2015; Tseng et al., 2017; Cui, 2018b). DEMATEL has been broadly integrated with other methods to expand its application. For instance, DEMATEL, AHP and TOPSIS are combined to assess green suppliers (Büyüközkan and Çifçi, 2012), and DEMATEL and ANP have been integrated to assess and identify renewable resources (Sangaiah et al., 2017). DEMATEL is flexible as a stand-alone or mixed-model tool, with a number of recent advances.

In most previous DEMATEL applications, the theoretical basis for the evaluation of influencing factors has been lacking. We use synergetic theory as a theoretical lens to develop the assessment framework of cross-border SCC. Simultaneously, we use vague sets to enhance the processing of fuzzy information in DEMATEL (Zhang et al., 2009; Leksono et al., 2018). We combine vague sets and DEMATEL to address the fuzzy nature and uncertainty of expert semantics (Geng and Chu, 2012). In addition, we propose a combination weighting method that further supports the influencing factors. Integrating an additional appropriate weighting of factors can more effectively evaluate the interdependence of various factors (Tseng et al., 2014).

3. Methodology

To assess the influencing factors of cross-border SCC, we propose a combination weighting approach. The illustration is shown in Figure 1.

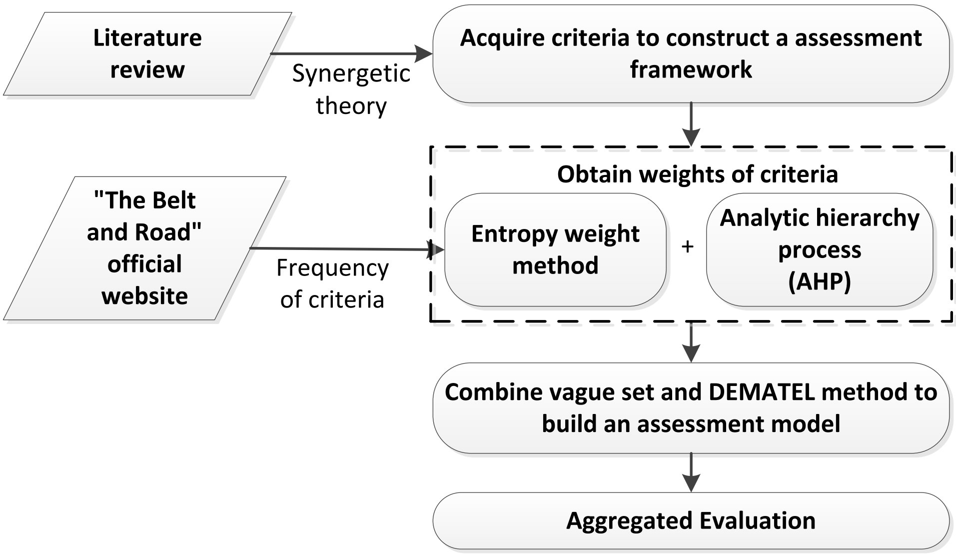


Fig. 1 Illustration of Proposed Methodology

The details are as follows.

Step 1: Criteria acquisition and assessment framework construction

A literature review is a reliable and effective way to identify key topics in research areas and can be used to guide a qualitative data analysis (Chan et al., 2016). Based on a comprehensive review of the literature, through a synergetic theory lens, the factors that relate to cross-border SCC were determined. According to synergetic theory, the resulting assessment framework has the three aspects of internal subsystems, inter-subsystems and external systems.

Step 2: Weighting of the criteria based on a combination weighting method

To make the weighting more reasonable, combination weighting, based on game theory (Yu et al., 2012), is introduced. Objective weighting (data crawler) and subjective weighting (AHP) are combined to determine the criteria weights.

Step 2a: Use a digital information data crawler for objective weighting.

Websites and internet data are windows to transmit information. The information provided by the BRI and related documents can help to determine the objective importance of criteria. Data crawlers are effective tools for obtaining large amounts of website data (Yang et al., 2009). This data can be analysed with word frequency statistics for the SCC criteria. This data crawler information is used to develop entropy weights.

We first use a Python crawler to obtain website text. We then process the word segments, select the words related to the criteria and count the word frequency, which is denoted as R_p $(p = 1,2,\cdots,q)$, where q is the number of criteria. A normalization of these frequencies is completed by using expression (1).

$$\hat{R}_p = \frac{R_p}{\sum_{p=1}^{q} R_p} \tag{1}$$

The second stage in this sub-step is to calculate the entropy for a criterion $\hat{R}_p^e$ using expression (2) (Liu et al., 2015).

$$\hat{R}_p^e = -\frac{1}{\ln(q)} \times \sum_{p=1}^{q}[\hat{R}_p \times \ln(\hat{R}_p)] \tag{2}$$

Expression (3) is then used to calculate the objective weights for each criterion ω_p':

$$\omega_p' = \frac{1-\hat{R}_p^e}{\sum_{p=1}^{q}(1-\hat{R}_p^e)} \tag{3}$$

where $\sum_{p=1}^{q}\omega_p' = 1$.

Step 2b: Use AHP for subjective weighting.

AHP uses the experience and knowledge of experts and their judgements and reasoning to determine the factor weightings (Yurdakul and Ic, 2005).

Stage 1: Construct a pairwise comparison matrix of the factors

The expert group evaluates the factors in pairs and builds judgement matrix A (4).

$$\mathrm{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad i = 1,2,\cdots,n;\ j = 1,2,\cdots,n \tag{4}$$

where *n* is the number of criteria, and a_{ij} indicates the importance of factor *i* when compared with factor *j* on an overall category or aspect. The diagonal elements have a score of 1, and the elements in the upper right and lower left corners are reciprocal, where $a_{ij} = 1/a_{ji}$. The values of a_{ij} are from 1/9 to 9, and a larger value indicates a higher level of importance.

Stage 2: Calculate the eigenvector of weights W

The maximum eigenvalue λ_{max} and the eigenvector ω of matrix A are obtained according to expression (5). The obtained feature vector W is normalized to obtain the order of importance of each criterion, that is, the subjective weight ω'' distribution.

$$\mathrm{A}W = \lambda_{max}W \tag{5}$$

Step 2c: Combine the objective and subjective weights.

The combination weighting method aggregates the two weighting methods to arrive at a general weight. It is assumed that the weights calculated by the frequency of the criteria are $\omega' = (\omega_1', \omega_2', \cdots, \omega_n')$ and $0 \le \omega' \le 1, \sum \omega_n' = 1$. The weights obtained by AHP are $\omega'' = (\omega_1'', \omega_2'', \cdots, \omega_n'')$ and $0 \le \omega'' \le 1, \sum \omega_n'' = 1$. Thus, the combined weights can be obtained by using expression (6) (Yu et al., 2012):

$$\omega = \alpha\omega' + \beta\omega'' \text{ and } \alpha, \beta \ge 0, \alpha + \beta = 1 \tag{6}$$

where *α* denotes the ratio of the subjective weight to the combined weight, and *β* denotes the ratio of the objective weight to the combined weight.

In this paper, we set the two ratios as equal ($\alpha = \beta = 0.5$) (Li et al., 2016); thus, we get expression (7).

$$\omega = 0.5\omega' + 0.5\omega'' \tag{7}$$

Step 3: Assessment analysis of the causal relationship among the criteria by vague DEMATEL with mixed weights

Step 3a: By using expert opinions, the relationships among the criteria are compared. Each criterion is defined as C_i $(i = 1,2,\cdots,n)$. The initial relationship matrix C of the criteria is constructed with matrix (8).

$$\mathrm{C}=\begin{bmatrix}0 & c_{12} & \cdots & c_{1n}\\ c_{21} & 0 & \cdots & c_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ c_{n1} & c_{n2} & \cdots & 0\end{bmatrix}\quad i=1,2,\cdots,n;\ j=1,2,\cdots,n \tag{8}$$

where c_{ij} is the degree to which c_i affects c_j.

Step 3b: Transformation of the vague matrix and standardization

The criteria are assessed by *k* experts denoted as $\mathrm{C}^k=[\alpha_{ij}^k]_{n\times n}$. $\alpha_{ij}^k=[l_{op}^k,u_{op}^k]$ represents the transformed vague numbers in Table 1 (Geng et al., 2010). l_{op}^k is the lower bound and u_{op}^k is the upper bound of the vague valuation. θ and φ represent the higher and lower level hesitancy degrees, respectively. These values are pre-determined, where $\theta+\varphi=1$. ε is the hesitancy degree; 0.2 is adopted in this study (Cui et al., 2018a). Therefore, the individual criteria vague matrix is expressed by matrix (9).

$$\mathrm{C}^k=[\alpha_{ij}^k]_{n\times n}=\begin{bmatrix}0 & \alpha_{12}^k & \cdots & \alpha_{1n}^k\\ \alpha_{21}^k & 0 & \cdots & \alpha_{2n}^k\\ \vdots & \vdots & \ddots & \vdots\\ \alpha_{n1}^k & \alpha_{n2}^k & \cdots & 0\end{bmatrix} \tag{9}$$

where *k* is the index for expert *k*.

Table 1 Linguistic scales for transferring vague numbers.

Linguistic terms	**Linguistic preferences**	**Contrasting vague numbers**$[\boldsymbol{l_{op}},\boldsymbol{u_{op}}]$	**θ**	***φ***
NI	No Influence	[0.1-θ×ε,0.1+φ×ε]	0	1
LI	Low Influence	[0.3-θ×ε,0.3+φ×ε]	0.5	0.5
MI	Medium Influence	[0.5-θ×ε,0.5+φ×ε]	0.5	0.5
HI	High Influence	[0.7-θ×ε,0.7+φ×ε]	0.5	0.5
VI	Very High Influence	[0.9-θ×ε,0.9+φ×ε]	1	0

The individual vague matrix C^k is standardized into $\mathrm{D}^k=[l_{ij}^k,u_{ij}^k]_{n\times n}$ by using expressions (10) and (11).

$$l_{ij}^k=\left(l_{op}^k-\min l_{op}^k\right)/\Delta_{min}^{max} \tag{10}$$

$$u_{ij}^k=\left(u_{op}^k-\min l_{op}^k\right)/\Delta_{min}^{max} \tag{11}$$

where$\Delta_{min}^{max}=\max u_{op}^k-\min l_{op}^k$

$\max u_{op}^k$ is the maximum upper value among the upper bound of vague number values for expert *k*, and $\min l_{op}^k$ is the minimum lower value among the lower bound of vague number values for expert k.

Step 3c: Calculate the total normalized crisp values for each expert k and overall crisp matrix.

Calculate the total normalized crisp values (v_{ij}^k) for each expert *k* by using expression (12).

$$v_{ij}^k=\left[l_{ij}^k\left(1-l_{ij}^k\right)+\left(u_{ij}^k\right)^2\right]/\left[1-l_{ij}^k+u_{ij}^k\right] \tag{12}$$

Then compute crisp values z_{ij}^{k} with expression (13).

$$z_{ij}^{k} = minl_{op}^{k} + v_{ij}^{k} * \Delta_{min}^{max} \tag{13}$$

According to the opinions of various experts, all crisp value matrices are aggregated into a single overall crisp matrix Z by using expression (14).

$$\mathrm{Z} = [z_{ij}]_{n\times n} = \left(z_{ij}^{1} + z_{ij}^{2} + \cdots + z_{ij}^{k}\right)/k \tag{14}$$

where *k* is the number of experts.

Step 3d: Calculate the normalized direct relation matrix.

The normalized direct relation matrix (P) is obtained through expression (15). The collective effect γ is calculated with expression (16).

$$P = \gamma.\mathrm{Z} \tag{15}$$

$$\gamma = \frac{1}{\max\limits_{1\le i\le n}(\sum_{j=1}^{n}\alpha_{ij})} \tag{16}$$

Step 3e: Calculate the relation matrix (M) for integrating the weights.

The weights obtained by the combination weighting method are incorporated into the normalized matrix. The relation matrix (M) is obtained through expression (17).

$$\mathrm{M} = \mathrm{P} \otimes \omega \tag{17}$$

Step 3f: Calculate the total relation matrix (T) by using expression (18).

$$\mathrm{T} = \mathrm{M}(I - \mathrm{M})^{-1} \tag{18}$$

where *I* is the identity matrix.

Step 3g: Calculate row (R) and column (D) sums.

From the total relation matrix (T), the (R) and (D) can be calculated with (19) and (20).

$$R = \sum_{j=1}^{n} t_{ij} \tag{19}$$

$$D = \sum_{i=1}^{n} t_{ij} \tag{20}$$

Step 3h: Produce a cause and effect diagram by using the data set (*R* + *D*, *R* - *D*).

4. Case Illustrative Application

4.1 Theoretical measures

First, according to synergetic theory, the system forms a self-organizing structure that develops spontaneously to the optimal state under the influence of the external systems' environment and internal subsystems. The self-organizing structure is achieved through the coordination of internal subsystems and direct feedback of information under the interference of other factors from external systems (Li, 2017b). SCC can be considered to be this type of system that requires the interaction of internal subsystems and external systems. Based on this theoretical perspective, we introduce three major dimensions or aspects – namely, intra-subsystems, inter-subsystems, and external systems (see Table 1). The intra-subsystems dimension includes the factors coming from inside each firm. The inter-subsystems dimension mainly considers the relationships between supply chain members, while the external systems dimension involves the external environment of the whole supply chain. These aspects comprehensively cover the SCC system and support the establishment of criteria.

Intra-subsystems (A1) have a number of factors that influence SCC. Information technology usage (C1) plays an important role in SCC (Wu and Chiu, 2018). Firms are increasingly using advanced enterprise-level information technology to improve collaboration across the supply chain (Bharadwaj et al., 2007). Management information systems and supply chain management technologies are examples (Lin, 2014; Youn et al., 2014; Wu and Chiu, 2015).

Many failures in SCC are caused by incompatible organizational cultures (Ribbink and Grimm, 2014; Parker and Anderson, 2010). Thus, organizational culture compatibility (C2) is an important factor to consider (Zhang and Cao, 2018). SCC is positively related to operating performance (C3) measures, such as lower cost, better quality, faster delivery, and consistent delivery (Hartley et al., 2014). Sustainability has also received increasing attention in the business field. The natural environmental practices (C4) of firms are key issues in supply chain management (Lindgreen et al., 2010; Tate et al., 2010; Chen et al., 2017). For organizations to improve SCC and further the supply chain management strategy, senior manager support (5) (Chen and Paulraj, 2004; Stanley et al., 2011), such as finance or policy, is required.

The next subsystems to be included are the subsystems that connect to inter-organizational relationships – i.e., inter-subsystems (A2). Information sharing (C6) is a factor for effective SCC (Yaibuathet et al., 2008). Supply chain partners can improve overall supply chain competitiveness and thereby enhance their own competitive advantage through information sharing. As different stakeholders, firms often have conflicts due to profit allotment (C7). A reasonable profit allotment can not only reduce the occurrence of conflicts but also motivate firms in the supply chain and increase mutual trust (Zhong et al., 2007; Ding et al., 2011). Trust between firms is an underlying premise for cooperative behaviour. The degree of trust (C8) has a positive correlation with collaboration (Lui et al., 2009; Hewett and Bearden, 2001). Studies have shown that mutual trust between firms in a supply chain can promote the flexibility of communication, which further promotes SCC. Improving goal consistency (C9) among supply chain members can improve partners' satisfaction when seeking to achieve their own goals. It can also encourage them to perform their respective collaboration roles more effectively (Cao and Zhang, 2011). Collaborative agreements (C10) can provide guarantees for SCC by resolving contradictions and conflicts (Ven, 1992; Simatupang and Sridharan, 2011; Motlhagodi and Motlhagodi, 2018).

External systems of SCC (A3) refer to the external supply chain environment. These typically include factors that supply chains cannot directly control. A cross-border supply chain has higher levels of complexity and uncertainty because of its particular cross-border nature. Increasing market competition (C11), especially due to globalization, is a powerful driving force for firms to seek world-class suppliers and conduct cross-border SCC (Hahn et al., 1990; Simatupang and Sridharan, 2002; Rezapour et al., 2016).

Free-trade agreements (C12) and trade policy in general between different countries promote the development of regional, comprehensive economic partnerships. These agreements influence transnational trade, which thus accelerates the development of global supply chains (Chen and Paulraj, 2004; Chiang, 2018). Legal guarantees (C13) provide protections of basic rights and behavioural standards for firms to conduct cross-border SCC (Child et al., 2003; Rahim, 2017; Parry and Gao, 2018). Policy support (C14), such as security policy and procurement policy, affects trade facilitation and thus affects the competitiveness of cross-border supply chains (Cedillo-Campos et al., 2014; Bueno-Solano and Cedillo-Campos, 2014). Customs regulation (C15) directly affects not only the transportation of cross-border goods but also the collaboration development of the entire cross-border supply chain (Hintsa and Hameri, 2009). Regional security (C16) is also a basic and important condition for cross-border SCC (Hintsa and Hameri, 2009).

Accordingly, the proposed aspects and criteria of cross-border SCC are summarized in Table 2.

Table 2 Proposed aspects and criteria of cross-border SCC.

Aspects	**Criteria**	**Reference**
Intra-subsystems (A1)	Information technology usage (C1)	Wu and Chiu (2018), Bharadwaj et al. (2007), Lin (2014), Youn et al. (2014), Wu and Chiu (2015)
	Organizational culture compatibility (C2)	Lindgreen et al. (2010), Tate et al. (2010), Chen et al. (2017)
	Operating performance (C3)	Hartley et al. (2014)
	Natural environmental practices (C4)	Chen and Paulraj (2004), Stanley et al. (2011)
	Senior manager support (C5)	Ribbink and Grimm (2014), Parker and Anderson (2010), Zhang and Cao (2018)
Inter-subsystems (A2)	Information sharing (C6)	Yaibuathet et al. (2008)
	Profit allotment (C7)	Zhong et al. (2007), Ding et al. (2011)
	Degree of trust (C8)	Lui et al. (2009), Hewett and Bearden (2001)
	Goal congruence (C9)	Ven (1992) Simatupang and Sridharan (2011), Motlhagodi and Motlhagodi (2018)
	Collaborative agreements (C10)	Cao and Zhang (2011)
External systems (A3)	Market competition (C11)	Chen and Paulraj (2004), Chiang (2018)
	Free-trade area agreements (C12)	Hahn et al. (1990), Simatupang and Sridharan (2002), Rezapour et al. (2016)
	Legal guarantees (C13)	Child et al. (2003), Rahim (2017), Parry and Gao (2018)
	Policy support (C14)	Cedillo-Campos et al. (2014), Bueno-Solano and Cedillo-Campos

	(2014)
Customs regulation (C15)	Hintsa and Hameri (2009)
Regional security (C16)	Hintsa and Hameri (2009)

4.2 Methodological application

First, the Belt and Road Portal is the official website portal for promoting BRI construction. It contains domestic and foreign news and international cooperation information, such as cross-border capital flow trends, domestic and foreign investment information, real-time policy changes and policy interpretations. The portal also has important basic data on its information sharing platform for solving the problems of cross-border practices (Qian, 2017). To determine the importance of the criteria in the BRI context, this paper crawls the content of relevant policy documents from the website and obtains the objective weights of the criteria of cross-border SCC through the word frequency statistical calculation.

Second, the empirical data are collected through expert questionnaires. The panel has 10 experts. Among them, seven experts are managers of large state-owned or multinational companies. These companies are involved in BRI related businesses. These seven experts have more than 20 years of work experience in international trade. The other three experts are academic experts from the field of supply chain management, and they study the BRI. They have engaged in related research for more than 5 years. The specific information of the experts is shown in Table 3.

Table 3 Demographic information of the experts

Experts	Position	Work experience (Years)	Role/ Research Direction
Expert 1	Supply Chain Manager	21	Cross-border trade, building materials
Expert 2	Supply Chain Manager	24	Cross-border logistics
Expert 3	Assistant Supply Chain Manager	22	Cross-border goods leasing
Expert 4	Supply Manager	21	Management of contract and warehouse
Expert 5	Senior Procurement Manager	27	Cross-border transportation and sea transportation
Expert 6	Financial Manager	23	Cross-border financial leasing
Expert 7	Supply Manager	24	Cross-border electricity supplier
Expert 8	Professor in Policy Research	10	Policy research, cross-border E-commerce
Expert 9	Professor in Operational Management	8	Supply chain management, cross-border supply chain
Expert 10	Professor in Supply Chain Management	6	Green supply chain and supply chain coordination

Next is the procedure for assessing and analysing the influencing factors of the cross-border SCC against the BRI background.

(1) The "policy environment" section of the BRI Portal is chosen. The data crawler obtains the website content from the BRI Portal. Key word frequencies related to each criterion are obtained by word segmentation and word frequency statistics. By using expressions (1) - (3), the objective weights are calculated. The frequency of the criteria and the transformed entropy weights are

summarized in Table 4.

Table 4 The frequency of the criteria and the transformed entropy weights.

Criteria	Frequency	Normalized	Entropy	Entropy Weights
C1	36	0.027	0.965	0.064
C2	208	0.157	0.895	0.059
C3	7	0.005	0.990	0.066
C4	145	0.109	0.913	0.060
C5	86	0.065	0.936	0.062
C6	19	0.014	0.978	0.065
C7	52	0.039	0.954	0.063
C8	56	0.042	0.952	0.063
C9	49	0.037	0.956	0.063
C10	128	0.096	0.919	0.061
C11	24	0.018	0.974	0.065
C12	35	0.026	0.965	0.064
C13	71	0.054	0.943	0.063
C14	98	0.074	0.931	0.062
C15	208	0.157	0.895	0.059
C16	105	0.079	0.928	0.061

(2) The AHP questionnaire is sent to experts. The experts are asked to compare and score the criteria in pairs. According to the experience of each expert, we assign equal weight to each expert. Then the judgements of the experts are aggregated by calculating the mean values. The judgement matrix A (aggregated matrix) is shown in Table 5.

Table 5 Judgement matrix A.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	1.000	1.000	1.000	2.000	1.000	1.000	1.000	1.000	1.000	2.000	1.000	2.000	4.000	1.000	1.000	7.000
C2	1.000	1.000	1.000	2.000	2.000	1.000	1.000	1.000	1.000	2.000	1.000	2.000	4.000	1.000	1.000	7.000
C3	1.000	1.000	1.000	2.000	1.000	1.000	1.000	1.000	0.500	2.000	1.000	2.000	3.000	1.000	1.000	6.000
C4	0.500	0.500	0.500	1.000	1.000	0.500	0.500	0.500	0.500	1.000	0.500	1.000	2.000	1.000	1.000	4.000
C5	1.000	0.500	1.000	1.000	1.000	0.500	0.500	0.500	0.500	1.000	1.000	2.000	3.000	1.000	1.000	5.000
C6	1.000	1.000	1.000	2.000	2.000	1.000	1.000	1.000	1.000	2.000	1.000	3.000	4.000	2.000	2.000	8.000
C7	1.000	1.000	1.000	2.000	2.000	1.000	1.000	1.000	1.000	2.000	1.000	3.000	4.000	2.000	2.000	8.000
C8	1.000	1.000	1.000	2.000	2.000	1.000	1.000	1.000	1.000	2.000	1.000	3.000	4.000	2.000	2.000	8.000
C9	1.000	1.000	2.000	2.000	2.000	1.000	1.000	1.000	1.000	2.000	2.000	3.000	5.000	2.000	2.000	9.000
C10	0.500	0.500	0.500	1.000	1.000	0.500	0.500	0.500	0.500	1.000	0.500	1.000	2.000	1.000	1.000	4.000
C11	1.000	1.000	1.000	2.000	1.000	1.000	1.000	1.000	0.500	2.000	1.000	2.000	3.000	1.000	1.000	6.000
C12	0.500	0.500	0.500	1.000	0.500	0.333	0.333	0.333	0.333	1.000	0.500	1.000	2.000	0.500	0.500	3.000
C13	0.250	0.250	0.333	0.500	0.333	0.250	0.250	0.250	0.200	0.500	0.333	0.500	1.000	0.500	0.500	2.000
C14	1.000	1.000	1.000	1.000	1.000	0.500	0.500	0.500	0.500	1.000	1.000	2.000	2.000	1.000	1.000	5.000
C15	1.000	1.000	1.000	1.000	1.000	0.500	0.500	0.500	0.500	1.000	1.000	2.000	2.000	1.000	1.000	5.000

C16	0.143	0.143	0.167	0.250	0.200	0.125	0.125	0.125	0.111	0.250	0.167	0.333	0.500	0.200	0.200	1.000

With expressions (4) and (5), the subjective weights are determined and summarized in Table 6.

Table 6 The subjective criteria weights.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**
ω	0.077	0.081	0.072	0.044	0.055	0.091	0.091	0.091	0.102	0.044	0.072	0.035	0.022	0.056	0.056	0.011

(3) By using expression (7), the combination weights are obtained (see Table 7).

Table 7 The combination weights of the criteria.

Criteria	**Objective weights (ω')**	**Subjective weights (ω'')**	**Combination weights (ω)**
C1	0.064	0.077	0.071
C2	0.059	0.081	0.070
C3	0.066	0.072	0.069
C4	0.060	0.044	0.052
C5	0.062	0.055	0.059
C6	0.065	0.091	0.078
C7	0.063	0.091	0.077
C8	0.063	0.091	0.077
C9	0.063	0.102	0.082
C10	0.061	0.044	0.053
C11	0.065	0.072	0.068
C12	0.064	0.035	0.049
C13	0.063	0.022	0.042
C14	0.062	0.056	0.059
C15	0.059	0.056	0.058
C16	0.061	0.011	0.036

(4) The obtained expert questionnaire data are processed with expression (8). The initial relationship matrix of expert k=1 is shown as an example in Table 8; other experts may have different scores but are similarly structured.

Table 8 The initial/direct relationship matrix C of expert k=1.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**
C1	0	MI	HI	HI	HI	HI	LI	HI	MI	MI	MI	LI	LI	LI	LI	MI
C2	HI	0	HI	MI	HI	VI	HI	HI	HI	HI	MI	MI	LI	LI	LI	LI
C3	HI	MI	0	HI	HI	MI	VI	VI	VI	VI	HI	HI	MI	HI	HI	MI
C4	NI	LI	HI	0	HI	LI	HI	LI	LI	LI	MI	MI	LI	HI	HI	MI
C5	VI	VI	VI	HI	0	VI	VI	VI	HI	VI	LI	MI	LI	LI	MI	NI
C6	HI	LI	HI	HI	HI	0	MI	HI	HI	HI	HI	HI	HI	HI	HI	HI

C7	LI	HI	HI	MI	HI	HI	0	HI	HI	HI	HI	HI	MI	MI	HI	HI
C8	HI	HI	HI	LI	HI	HI	HI	0	HI	HI	HI	HI	HI	MI	MI	HI
C9	MI	VI	HI	MI	HI	HI	HI	VI	0	VI	HI	HI	HI	MI	MI	MI
C10	MI	HI	HI	MI	HI	HI	HI	HI	HI	0	MI	HI	HI	HI	HI	HI
C11	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	0	VI	VI	VI	VI	VI
C12	HI	MI	HI	MI	MI	HI	HI	HI	HI	HI	VI	0	VI	VI	VI	VI
C13	VI	VI	VI	VI	VI	VI	HI	HI	MI	HI	VI	VI	0	VI	VI	VI
C14	VI	HI	VI	VI	HI	VI	MI	MI	MI	MI	HI	HI	HI	0	HI	HI
C15	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	0	VI
C16	HI	HI	VI	MI	HI	HI	MI	VI	HI	VI	HI	HI	VI	VI	VI	0

By using the vague numbers in Table 1, each initial/direct relationship linguistic matrix is converted into a corresponding vague numbers matrix with expression (9), and the standardized vague matrix (D) of expert *k=1* is obtained through expressions (10) and (11) with the results shown in Table 9.

Table 9 Standardized vague matrix D of expert k=1.

	C1	**C2**	**C3**	**…**	**C15**	**C16**
C1	[0.000,0.000]	[0.444,0.667]	[0.667,0.889]	**…**	[0.222,0.444]	[0.444,0.667]
C2	[0.667,0.889]	[0.000,0.000]	[0.667,0.889]	**…**	[0.222,0.444]	[0.222,0.444]
C3	[0.667,0.889]	[0.444,0.667]	[0.000,0.000]	**…**	[0.667,0.889]	[0.444,0.667]
C4	[0.111,0.333]	[0.222,0.444]	[0.667,0.889]	**…**	[0.667,0.889]	[0.444,0.667]
C5	[0.778,1.000]	[0.778,1.000]	[0.778,1.000]	**…**	[0.444,0.667]	[0.111,0.333]
C6	[0.667,0.889]	[0.222,0.444]	[0.667,0.889]	**…**	[0.667,0.889]	[0.667,0.889]
C7	[0.222,0.444]	[0.667,0.889]	[0.667,0.889]	**…**	[0.667,0.889]	[0.667,0.889]
C8	[0.667,0.889]	[0.778,1.000]	[0.667,0.889]	**…**	[0.444,0.667]	[0.667,0.889]
C9	[0.444,0.667]	[0.778,1.000]	[0.667,0.889]	**…**	[0.444,0.667]	[0.444,0.667]
C10	[0.444,0.667]	[0.667,0.889]	[0.667,0.889]	**…**	[0.667,0.889]	[0.667,0.889]
C11	[0.778,1.000]	[0.778,1.000]	[0.778,1.000]	**…**	[0.778,1.000]	[0.778,1.000]
C12	[0.667,0.889]	[0.444,0.667]	[0.667,0.889]	**…**	[0.778,1.000]	[0.778,1.000]
C13	[0.778,1.000]	[0.778,1.000]	[0.778,1.000]	**…**	[0.778,1.000]	[0.778,1.000]
C14	[0.778,1.000]	[0.667,0.889]	[0.778,1.000]	**…**	[0.667,0.889]	[0.667,0.889]
C15	[0.778,1.000]	[0.778,1.000]	[0.778,1.000]	**…**	[0.000,0.000]	[0.778,1.000]
C16	[0.667,0.889]	[0.667,0.889]	[0.778,1.000]	**…**	[0.778,1.000]	[0.000,0.000]

Then, each expert's initial standardized vague matrix D is transformed into a crisp numbers matrix by using expressions (12) and (13). They are further aggregated into an overall crisp value matrix Z with expression (14); these steps are not shown. The normalized direct relation matrix P is calculated by using the aggregated matrix Z and applying expressions (15) and (16). The resulting normalized direct relation matrix P is shown as Table 10.

Table 10 Normalized direct relation matrix P.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**

C1	0	0.58	0.757	0.596	0.652	0.823	0.391	0.565	0.55	0.556	0.621	0.394	0.481	0.441	0.396	0.581
C2	0.484	0	0.609	0.47	0.778	0.624	0.701	0.696	0.616	0.672	0.501	0.468	0.339	0.373	0.398	0.529
C3	0.555	0.617	0	0.461	0.766	0.506	0.71	0.69	0.672	0.698	0.764	0.518	0.517	0.538	0.772	0.534
C4	0.385	0.435	0.553	0	0.432	0.369	0.438	0.482	0.432	0.496	0.488	0.439	0.669	0.495	0.734	0.519
C5	0.955	0.813	0.866	0.764	0	0.647	0.879	0.865	0.715	0.681	0.595	0.501	0.521	0.507	0.635	0.491
C6	0.749	0.466	0.556	0.526	0.661	0	0.485	0.578	0.659	0.608	0.619	0.548	0.434	0.525	0.524	0.662
C7	0.353	0.593	0.688	0.311	0.761	0.521	0	0.621	0.642	0.721	0.681	0.4	0.502	0.313	0.699	0.446
C8	0.463	0.591	0.661	0.365	0.774	0.681	0.643	0	0.655	0.717	0.523	0.544	0.5	0.398	0.544	0.566
C9	0.553	0.725	0.836	0.432	0.736	0.765	0.59	0.687	0	0.696	0.514	0.518	0.472	0.364	0.441	0.523
C10	0.422	0.634	0.639	0.44	0.695	0.678	0.59	0.703	0.695	0	0.625	0.616	0.534	0.413	0.586	0.528
C11	0.726	0.702	0.823	0.721	0.776	0.678	0.776	0.67	0.682	0.805	0	0.608	0.652	0.533	0.571	0.542
C12	0.39	0.447	0.613	0.528	0.521	0.604	0.538	0.578	0.601	0.734	0.711	0	0.584	0.582	0.638	0.771
C13	0.514	0.58	0.648	0.751	0.607	0.588	0.56	0.627	0.573	0.7	0.658	0.745	0	0.707	0.816	0.838
C14	0.37	0.475	0.629	0.496	0.526	0.573	0.53	0.507	0.483	0.608	0.651	0.687	0.785	0	0.651	0.664
C15	0.621	0.578	0.783	0.778	0.734	0.697	0.564	0.709	0.727	0.73	0.839	0.798	0.817	0.773	0	0.804
C16	0.561	0.496	0.643	0.541	0.511	0.615	0.517	0.771	0.731	0.779	0.672	0.642	0.706	0.627	0.704	0

The relation matrix M is computed by using the normalized direct relation matrix P and applying expression (17). Then, the total relation matrix T is calculated with expression (18). The results of the total relation matrix T are shown in Table 11.

Table 11 The total relation matrix T.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**
C1	0.0002	0.0039	0.0050	0.0030	0.0037	0.0060	0.0030	0.0042	0.0044	0.0028	0.0041	0.0019	0.0020	0.0025	0.0022	0.0020
C2	0.0033	0.0002	0.0040	0.0024	0.0043	0.0046	0.0051	0.0051	0.0049	0.0034	0.0033	0.0022	0.0014	0.0021	0.0023	0.0018
C3	0.0038	0.0041	0.0002	0.0023	0.0043	0.0038	0.0052	0.0051	0.0053	0.0035	0.0050	0.0025	0.0021	0.0030	0.0042	0.0019
C4	0.0026	0.0029	0.0037	0.0001	0.0025	0.0028	0.0033	0.0036	0.0034	0.0025	0.0032	0.0021	0.0027	0.0028	0.0040	0.0018
C5	0.0064	0.0054	0.0057	0.0038	0.0002	0.0049	0.0064	0.0063	0.0057	0.0035	0.0039	0.0024	0.0021	0.0029	0.0035	0.0018
C6	0.0050	0.0032	0.0037	0.0026	0.0037	0.0002	0.0036	0.0043	0.0052	0.0031	0.0040	0.0026	0.0018	0.0030	0.0029	0.0023
C7	0.0025	0.0040	0.0045	0.0016	0.0042	0.0039	0.0002	0.0046	0.0051	0.0036	0.0044	0.0019	0.0020	0.0018	0.0038	0.0016
C8	0.0032	0.0040	0.0044	0.0019	0.0043	0.0050	0.0047	0.0002	0.0052	0.0036	0.0035	0.0026	0.0020	0.0023	0.0030	0.0020
C9	0.0037	0.0048	0.0055	0.0022	0.0041	0.0056	0.0044	0.0050	0.0003	0.0035	0.0034	0.0025	0.0019	0.0021	0.0025	0.0018
C10	0.0029	0.0042	0.0042	0.0022	0.0039	0.0050	0.0044	0.0052	0.0055	0.0002	0.0041	0.0029	0.0022	0.0024	0.0033	0.0019
C11	0.0049	0.0047	0.0054	0.0036	0.0044	0.0051	0.0057	0.0050	0.0054	0.0040	0.0002	0.0029	0.0026	0.0030	0.0032	0.0019
C12	0.0027	0.0030	0.0041	0.0027	0.0030	0.0045	0.0040	0.0043	0.0048	0.0037	0.0046	0.0001	0.0024	0.0033	0.0035	0.0027
C13	0.0035	0.0039	0.0043	0.0037	0.0035	0.0044	0.0042	0.0046	0.0046	0.0035	0.0043	0.0035	0.0001	0.0040	0.0045	0.0029
C14	0.0026	0.0032	0.0042	0.0025	0.0030	0.0043	0.0039	0.0038	0.0039	0.0031	0.0042	0.0032	0.0031	0.0001	0.0036	0.0023
C15	0.0042	0.0039	0.0052	0.0039	0.0041	0.0052	0.0042	0.0052	0.0058	0.0037	0.0055	0.0037	0.0033	0.0043	0.0002	0.0028
C16	0.0038	0.0034	0.0043	0.0027	0.0029	0.0046	0.0039	0.0056	0.0058	0.0039	0.0044	0.0030	0.0028	0.0035	0.0039	0.0001

Subsequently, by using expressions (19) and (20), the row (R) and column (D) sums and the (R+D) and (R-D) values are calculated. The results are shown in Table 12.

Table 12 Prominence and relation axis of the criteria for the cause and effect groups.

	R	D	R+D	R-D
C1	0.051	0.055	0.106	-0.004
C2	0.050	0.059	0.109	-0.008
C3	0.056	0.068	0.125	-0.012
C4	0.044	0.041	0.085	0.003
C5	0.065	0.056	0.121	0.009
C6	0.051	0.070	0.121	-0.019
C7	0.050	0.066	0.116	-0.016
C8	0.052	0.072	0.124	-0.020
C9	0.053	0.075	0.128	-0.022
C10	0.054	0.052	0.106	0.003
C11	0.062	0.062	0.124	0.000
C12	0.053	0.040	0.093	0.013
C13	0.060	0.035	0.094	0.025
C14	0.051	0.043	0.094	0.008
C15	0.065	0.051	0.116	0.015
C16	0.059	0.031	0.090	0.027

In Table 12, (R+D) is "Prominence", which represents the importance of the criteria. Correspondingly, (R-D) is "Relation". If (R-D) is positive, the corresponding criteria are formulated into a cause group; otherwise, they are grouped into an effect group. By taking (R+D) as the horizontal axis and (R-D) as the vertical axis, the causal diagram of the criteria is depicted in Figure 2.

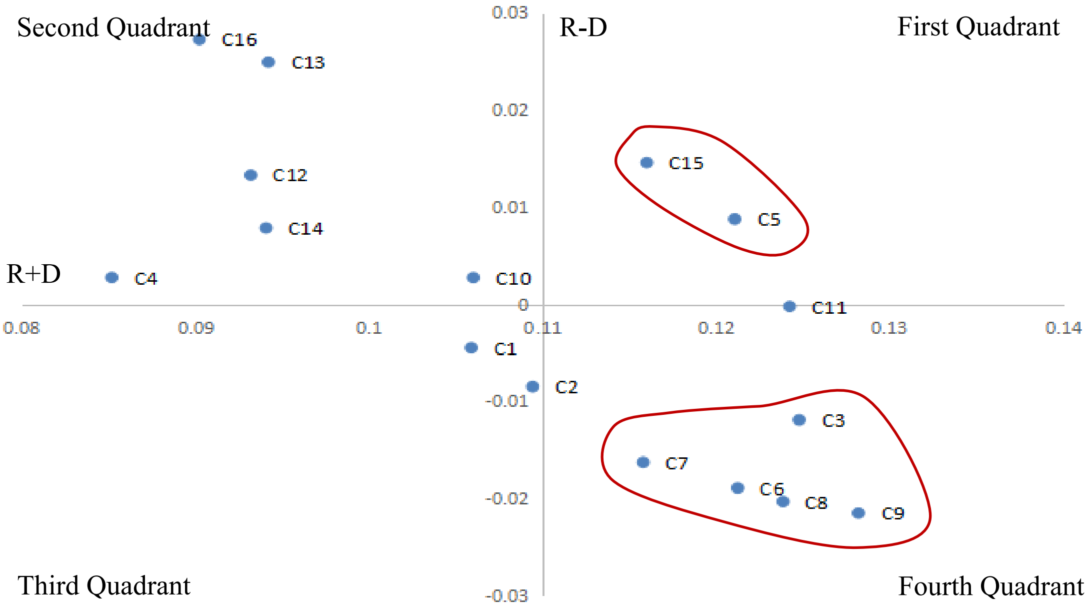


Figure 2 The Causal Diagram of the Criteria

In Figure 2, two determinant criteria, C15 and C5, are located in the first quadrant. Positive (R-D) values indicate that these criteria have a more significant impact on other criteria. The value of

(R + D) is positive, which indicates the importance of the criteria. These are the driving factors of cross-border SCC and have a greater influence and importance than the other criteria. They are considered to be the key factors that affect the cross-border SCC of firms. When the criteria are further into the upper right of a quadrant, the criteria are more critical. In addition, criteria C9, C8, C6, C7 and C3 in the fourth quadrant represent the core problems of cross-border SCC. They cannot directly affect the cross-border SCC of firms, but they have indirect influences through the criteria in the first quadrant. Therefore, firms should not ignore the criteria in this quadrant due to their prominence, although they are affected by other criteria.

4.3 Sensitivity analysis

In this paper, the criteria affecting cross-border SCC are analysed by combination weighting and vague DEMATEL methods. In order to check the robustness of the results (Xia et al., 2015), sensitivity analysis is completed.

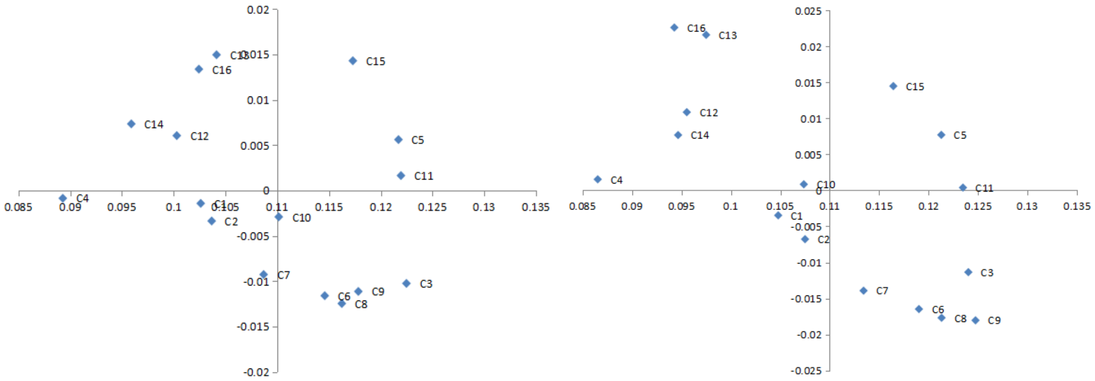
This study changes the weight of criteria by changing the proportions of subjective weights and objective weights (α and β) in the combination weight calculation. Four experiments are carried out. The values of α and β and the weights of the criteria in the four experiments are shown in Table 13. The experiments range from less to greater weight on subjective criteria.

Table 13 The values of α and β and the weights of criteria.

Criteria	**Experiment 1**	**Experiment 2**	**Experiment 3**	**Experiment 4**
Criteria	α=0.2 β=0.8	α=0.4 β=0.6	α=0.6 β=0.4	α=0.8 β=0.2
C1	0.064	0.077	0.071	0.071
C2	0.059	0.081	0.070	0.070
C3	0.066	0.072	0.069	0.069
C4	0.060	0.044	0.052	0.052
C5	0.062	0.055	0.059	0.059
C6	0.065	0.091	0.078	0.078
C7	0.063	0.091	0.077	0.077
C8	0.063	0.091	0.077	0.077
C9	0.063	0.102	0.082	0.082
C10	0.061	0.044	0.053	0.053
C11	0.065	0.072	0.068	0.068
C12	0.064	0.035	0.049	0.049
C13	0.063	0.022	0.042	0.042
C14	0.062	0.056	0.059	0.059
C15	0.059	0.056	0.058	0.058
C16	0.061	0.011	0.036	0.036

Using the above combination weights, we arrive at four causal diagrams. See Figure 3.

Experiment 1 **Experiment 2**



Experiment 3 **Experiment 4**

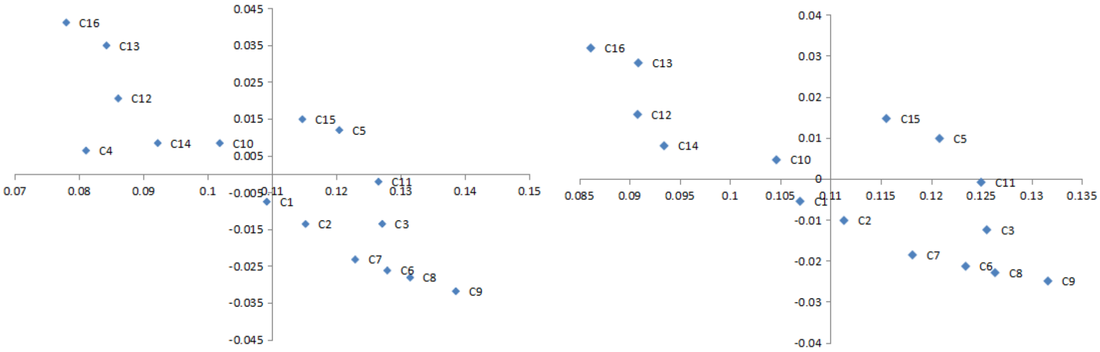


Figure 3 Sensitivity analysis plots

As shown in Figure 3, the causal diagrams obtained through the sensitivity analysis experiment are consistent with the overall causal diagram shown in Figure 2, confirming the robustness of the results of this study.

5. Theoretical and managerial implications

This study provides a number of theoretical and managerial implications for cross-border SCC researchers and practitioners. These implications are discussed in the next two sub-sections.

5.1 Theoretical implications

This study extends the literature on cross-border supply chain management in at least three directions. First, based on synergetic theory, it expands previous approaches that only consider the linkages among supply chain members by introducing the influence of members and their connections to the external environment. In this study, synergetic theory is used as the theoretical lens for proposing the three assessment aspects that comprise intra-subsystems, inter-subsystems and external systems. This comprehensive consideration is necessary for the firms that have limited resources and planning with large numbers of SCC practices. This categorization is an important initial theoretical contribution that can serve as a framework for further evaluation given the appropriate data. Furthermore, this study expands the application of synergetic theory into the supply chain management field and further strengthens the fundamental requirements of a theoretical evaluation and the monitoring of SCC practices.

Second, from a methodological perspective, this study’s integration of multiple tools into a unified methodology is beneficial to the analysis of cross-border supply chain collaboration in the

BRI context. The outcome of the proposed theoretical methodology is instructive. The DEMATEL method effectively identifies the causal relationships between the criteria. These relationships support critical factors and core issue analyses (Cui et al., 2018b). Vague sets extend the expressive power of traditional fuzzy sets and better express uncertain information (Lu et al., 2016). Vague DEMATEL is used as an assessment method. Determining the weight of each criterion is a key step in this method. Most studies use subjective empowerment based on expert professional knowledge and subjective judgement, which has limitations. Similarly, objective analysis is overly reliant on the data collected and sometimes fails to reflect decision makers' true beliefs. Therefore, we introduce a combination weighting method. More precisely, we use AHP to obtain subjective weights. Furthermore, to make the evaluation results more consistent with the content of the BRI, we use the entropy method – a data crawler – to obtain objective weights. The use of a data crawler is a methodological contribution that can help to evaluate how well objective data map to subjective data. This joint methodology not only comprehensively considers the advantages and disadvantages of the subjective and objective weighting methods but also effectively links the BRI to the cross-border SCC. The theoretical results here show that the objective data from this study well represent subjective managerial perspectives. This result is observed by the sensitivity analysis in Section 4.3 that there are no great shifts. Our methodology is valuable when concerning cross-border SCC against a BRI background and further effectively supports and supplements the theoretical modelling development of supply chain collaboration.

Third, from the research results, senior manager support (C5) and customs regulation (C15) are the two important driving factors of cross-border SCC. Indeed, whether SCC can be smoothly performed and achieves good results is closely related to the support from senior management. Customs is always an important institution for controlling various cargo entry and exit aspects. The BRI entails increased cross-border trade volume, which has become the consensus. However, we have a new discovery that C5 belongs to intra-subsystems (A1), and C15 belongs to external systems (A3); no driving factors belong to inter-subsystems (A2). We often think of collaboration as more inter-organizational behaviour. Some studies have also demonstrated the positive impact of these behaviours, such as information sharing, reasonable profit allotment and mutual trust, on supply chain collaboration (Hewett and Bearden, 2001; Yaibuathet et al., 2008; Ding et al., 2011). However, our research shows that information sharing (C6), profit allotment (C7), the degree of trust (C8) and goal congruence (C9) in the inter-subsystems (A2) are the core issues of cross-border SCC. This means that these factors cannot drive cross-border SCC directly. The reason may be that cross-border SCC under the BRI is more complicated that local SCC. Due to cultural and language barriers, it is difficult for co-operators from different countries to establish mutual trust, not to mention the smooth flow of information and reasonable profit distribution. Goals are also more difficult to achieve. Therefore, firms pay more attention to senior manager support (C5) in intra-subsystems and customs regulation (C15) in external systems because they are easier to achieve. More precisely, because of preferential policies, such as financial support initiated by the Belt and Road, managers have the ability to support cross-border SCC, and customs regulation also tends to favour Belt and Road countries. This perspective further reinforces that supply chain management is a strategic issue, not just an operational issue.

5.2 Managerial implications

There are also several managerial implications based on the assessment results. Practitioners of cross-border supply chains should pay full attention to and attempt to get the support of senior managers, because senior managers have more resources with the implementation of the BRI. Senior managers, even up to the 'C-suite', should realize the importance of developing cross-border SCC and actively plan and monitor these activities. Forming an atmosphere and culture suitable for the development of cross-border SCC is critical. Culture typically begins at the top of the managerial structure. Senior management teams should reinforce supportive and correct decisions in supply chain member relationships and collaboration. This reinforcement should aim to not only boost morale but also ensure the necessary organizational resources, such as financial support, policy guidance and information sharing, to support the development of cross-border SCC.

Cross-border SCC suggests new requirements for customs policies and practices, especially in the RBI context. The interaction between different members in the supply chain and customs management activities seems to be paramount for cross-border SCC. First, customs regulations are important means for ensuring stable cross-border SCC development. Countries should cooperate and improve their customs regulations to minimize inefficiencies. Standardized management processes and formulating cargo safety plans are potential areas for improvement. Second, not only are process improvements a good strategy but also the utilization of advanced technologies may prove to be invaluable. Low-cost and high-efficiency customs clearance conditions can be created to facilitate cross-border SCC. One example is blockchain technology, which has shown potential for customs improvement (Okazaki, 2018). Internally, firms should realize the importance of customs regulation to their cross-border business, increase their emphasis on customs, consciously comply with relevant regulations, and actively cooperate with customs departments. For the BRI, these customs-based activities and awareness will prove to be instrumental to long-term success.

As core issues, operating performance, information sharing, profit allotment, the degree of trust and goal congruence are also a concern for cross-border SCC. Operating performance directly affects the selection of collaborative partners as supply chain members. Firms should pay special attention to one another's performance in the process of supplier selection, which can guarantee long-term and stable collaboration. Firms should also strengthen operation performance and competitiveness to increase the probability of being selected. Cross border supply chains are more complex than general supply chains, and the degree of information sharing is more important to improve the effect of collaboration. Firms should fully consider the differences between one another and ensure information sharing through the agreement of communication frequency, the development of information feedback mechanisms and other methods (Zeng et al., 2007). From the aspect of profit distribution, partners should formulate more detailed distribution principles and adjust them dynamically with the continuous development of collaboration. In addition, long-term cooperation is conducive to the degree of trust between firms (Camarero Izquierdo and Gutiérrez Cillán, 2004). Partners should establish a common culture oriented by long-term strategic development to increase mutual trust. Firms should not only focus on short-term interests but also pay more attention to long-term collaboration development, encourage the communication between employees according to the differences, and promote the integration of a corporate culture. The development of cross-border SCC needs to be a consistent goal across the supply chain. Supply chain members need to believe that their goals will be an outcome of working towards the goals of the supply chain (Ryu and Yücesan, 2010). Firms can jointly formulate implementation plans by fully understanding the needs and capabilities and reasonably positioning the roles and responsibilities of partners to ensure goal congruence. In addition, firms in the supply chain should have a clear strategic goal for the SCC. Clear strategic goals can successfully guide collaborative planning, provide a focus for collaborative relationships, promote the interaction among members, and provide a roadmap for collaboration (Min et al. 2005).

6. Conclusion

The Belt and Road initiative (BRI) aims to create a platform for cooperation among countries based on historical land and water trade with China. The initiative provides a convenient mechanism for firms to develop cross-border business and activities. Cross-border SCC becomes more important for firms to improve their global competitiveness in this context. Exploring the influencing factors of cross-border SCC is an important research concern. However, although there are many studies that focus on SCC, the research that assesses the influencing factors of cross-border SCC, especially given the emergent and impactful BRI, are still lacking. This context sets the stage for this study, where the focus is not only on the BRI and cross-border SCC but also on introducing an innovative weighting approach to evaluate the cross-border SCC factors.

Synergetic theory informs a cross-border SCC assessment framework that incorporates intra-subsystems, inter-subsystems and external systems. A vague set DEMATEL approach is introduced as part of the assessment method to explore the factors' influences on and relationships in cross-border SCC. This vague DEMATEL approach utilizes the subjective expert assignments of weights to the criteria. To avoid the one-sidedness of single subjective weighting, we introduce a combination weighting method, which combines AHP with an entropy weighting method that uses an automated data crawler for BRI-related documents and provides a more objective approach for ranking.

The assessment results show that senior manager support in intra-subsystems is a main driving factor for cross-border SCC. Senior manager attention and involvement is paramount to cross-border SCC success. Strategic, financial and personnel support are necessary and need to be led by senior managers to promote cross-border SCC. Customs regulations play an important external subsystem role for cross-border SCC. Policy implications arise from this issue, and the cooperation between policy makers and senior management along the supply chain is critical. Policy makers for countries involved in the BRI need to collaborate. Improving the safety and efficiency of cargo customs clearance are both considered to be important. In addition, information sharing, profit allotment, the degree of trust and goal congruence in inter-subsystems are often seen as SCC determinants. However, our research results show that they are the core issues that do not promote cross-border SCC directly. They have indirect influences through senior manager support and customs regulations. Therefore, practitioners should attempt to improve these issues to help manage and bridge the cultural, political, geographical, and legal boundaries to gain more support from senior managers and policy makers.

There are still some limitations of this study. First, the criteria in this study primarily derive from the literature. The influencing factors and relationships of cross-border SCC are dynamic. As the program and relationships develop and the BRI matures, it is likely that the factors and their relative relationships will alter. This work is only a snapshot. In addition, as the research literature on cross-border SCC matures, additional theoretical perspectives and elements can be considered in the future. As practice matures, firm websites, third-party platforms, and expert interviews can each be further utilized. Clearly, there is a need to follow up this study longitudinally.

Methodologically, the tool in this paper is based on vague-DEMATEL, AHP, and entropy data crawling methodology. Additional variations and testing of the methodology are needed. Other tools and comparisons should be evaluated given the many extensive sets of tools available from a 'soft-computing' perspective.

Overall, this work sets the stage for further understanding one of the largest global supply chain initiatives. The BRI may change the world, and understanding it from a multifactor perspective, including sustainability, is valuable. Careful monitoring and investigation for global SCC is still needed. We help to build on this important field.

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