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The Multi-Level Hierarchical Structure of the Enablers for Supply Chain Resilience Using Cloud Model-DEMATEL–ISM Method

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Abstract: Companies must shift from traditional supply chain management thinking to addressing or preventing increases in vulnerability, uncertainty, and unforeseen supply chain disruptions facing complex global supply chains. Systems with a large number of elements may be susceptible to nonlinear interactions, perturbation of which may lead to serious impacts. Thus, there is an increasing need to determine the importance of individual elements and how these elements interact. Published studies of supply chain resilience (SCRes) do not clearly determine the hierarchical structure of factors, and the understanding of interactions between factors remains fragmented. In this study, we proposed a cloud model-DEMATEL−ISM method to overcome the disadvantages of traditional DEMATEL−ISM integration methods. The MICMAC method (cross-impact matrix multiplication applied to classification) was also used to classify the enablers of SCRes based on driving force and dependence force. We tested these approaches by studying the new energy vehicle industry in China. The results suggest that companies trying to strengthen SCRes should focus on enablers at the base layer with a high driving force, particularly the enablers of social capital, restructuring, risk management culture, information technology application, trust and collaboration, information sharing, and learning capability..

Keywords: supply chain resilience; DEMATEL–ISM; cloud model

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1. Introduction

Today's business environment is highly competitive, and the conditions have be-come increasingly volatile, uncertain, complex, and ambiguous (VUCA), leading to a continued increase in supply chain disruptions. Both the length and complexity of global supply chains have increased, with increased risk of disturbance [1,2]. Supply chain disruptions may be an unintended and unexpected triggering event that occurs in upstream suppliers, procurement, logistics, or in a combination, posing a serious threat to normal business operation [3]. Two years of the COVID-19 pandemic and this year's Russia–Ukraine war illustrate how global problems at one end of a supply chain can affect the other end. Many companies have experienced severe supply chain disruptions, but were able to recover in the short term [4]. Traditional supply chain management theories fail to cope with such risks, and scholars and practitioners have suggested that supply chain management theories must incorporate resilience [5,6]. There has been increased attention to supply chain resilience (SCRes), given the importance of SCRes in maintaining business continuity and enhancing competitiveness [7]. According to Walker and Salt [8], the idea of resilience is wide-ranging and originates in engineering, psychology, ecology, and disaster relief studies. As supply chains grow in size and complexity, there is in-creased need for measurement and monitoring. Companies must shift from traditional supply chain management thinking to addressing or preventing the increasing vulnerability, uncertainty, and unforeseen supply chain disruptions facing complex global supply chains [9,10].

The research questions and targets of this study are that systems with a large number of elements may be susceptible to nonlinear interactions, perturbations of which may lead to serious impacts. Thus, there is increased urgency to identify the importance of individual elements and how they interact [11–13] and to determine factors that enhance supply chain resilience [14]. Several studies have tried to identify and analyze the factors contributing to SCRes, but published studies have not clearly identified the hierarchical structure of factors and lack a comprehensive understanding of the interactions between factors [15]. Decision-Making Trial and Evaluation Laboratory (DEMATEL) is a factor analysis tool for complex system decision-making. This tool can be used to explore the cause–effect relationship and logical correlations between various factors in complex systems. Interpretive Structural Modeling (ISM) is a similar tool, which can express structured models of factors with intuitive multi-level hierarchical structural relationships. ISM and DEMATEL are well-suited for deep analysis of complicated problems with complex system issues and have been separately used in past studies [16]. ISM and DEMATEL are based on similar concepts and both reflect the influence on relationships between the factors based on the information in an expert evaluation matrix, but the two models can yield different results.

Zhao et al. [17] proposed a DEMATEL–ISM integration approach. They argued that because the total-relation matrix of DEMATEL contains more information than the reachability matrix of ISM, a transformation of the total-relation matrix to the reachability matrix can be applied to obtain the hierarchy structure of complex systems. This can reduce the complex computation to obtain a reachability matrix of ISM, and this DEMATEL−ISM integration method has been applied in many studies [18–20]. Similarly, fuzzy-DEMATEL–ISM integration [21] and grey-DEMATEL–ISM integration [22] methods have been used, because incorporation of the fuzzy/grey theory can improve the stochastic and ambiguity problems of concepts in the natural language through the membership function [23]. However, the choice of the membership function is subjective and may ignore the uncertainty of the membership function itself. In this study, the cloud model (proposed by Li et al. [24]) was selected as it better reflects the vagueness and randomness of the concept of uncertainty. Cloud models have been applied in many fields [25–29] due to the randomness and stability. The main advancement of this study was the successful integration of a cloud model with DEMATEL−ISM as a powerful analytic tool.

Overall, this study is the first demonstration of a cloud model-DEMATEL−ISM approach that address the limitations of the traditional DEMATEL−ISM integration method. The enablers of SCRes were analyzed using this approach to reveal the hierarchical structure and interactional relationships between enablers for the new energy vehicle industry in China. The results of this work may serve as a helpful guide for companies to strengthen supply chain resilience.

2. Enablers of SCRes, Concept definition, and Theoretical Basis

2.1. Enablers of SCRes

The classic definition of supply chain resilience is the ability to bounce back from supply chain disruptions to normal operation. Several authors have explored the enablers of SCRes [30]. Hollnagel et al. [31] classified enablers into three categories: proactive, con-current, and reactive. Proactive was used to describe the capability required for the pre-outage phase, including planning, anticipation, alerts, and preparation. Concurrent described the ability to respond quickly and deal with interference during the disruption phase. Reactive described the action required to recover to the original or desired state from the disruption. Hohenstein et al. [32] classified enablers as proactive, reactive, and both proactive and reactive. Proactive was defined as the ability to predict possible interruptions and plan activities to occur before disruptions, including preparation, proactively planning, prevention, and anticipation. Reactive describes the ability to respond effectively and quickly to mitigate disruptions. Being both proactive and reactive refers to properties that not only predict and prepare, but also allow rapid response to interference. Newer definitions of SCRes describe it as the ability to adapt, withstand, and flourish despite external unrest or adverse change [33], or as an organization's ability to respond and recover. SCRes is considered an anticipatory capability where organizations can anticipate and adapt to disruptions while responding, recovering, and ultimately learning from these disruption [34]. Systematic literature reviews have summarized SCRes research [35,36].

This study used a literature review and collected information from in-industry experts. This analysis led to the classification of enablers of SCRes into three categories, defined as follows: (1) Proactive enablers include risk management culture, redundancy, product diversity, social capital, and trust and collaboration. Risk management culture refers to the ability to detect early warnings, plan, evaluate, and avoid and control risks before a crisis. Redundancy and product diversity describe the maintenance of excess equipment or the capacity and alternative complementarity of multiple products to disperse SC disruption risks. Social capital refers to intangible resources generated from a company's interorganizational relationships that can improve effectiveness through cooperation between people. Trust and collaboration is the ability of supply chain entities to trust and cooperate effectively to mutual benefit. (2) Reactive enablers include information sharing, visibility, robustness and agility, velocity, and interoperability. Information sharing occurs when the collective of members in the supply chain can utilize and effectively share their available information resources. Visibility requires control of the whole SC operation process from end-to-end of the information system to reduce risks. Robustness and agility describe the ability to resist adverse conditions and evolve constantly, and the ability to sense dynamic market changes and react quickly to meet client needs. Velocity is defined as the speed of reaction to a disruption. Interoperability is rapid response relying on interchangeable standard processes so that people familiar with the operation can easily perform necessary functions at multiple locations. (3) Restorative enablers include logistics support, information technology (IT) application, resource configuration, restructuring, and learning capability. Logistics support provides companies with guarantees for the distribution and transportation of goods. IT applications (e.g., big data analysis and blockchain technology) can link and respond to unpredictable changes and disruptions across functions and organizations. Resource configuration refers to the ability to redirect internal and external resources to adapt to a changing business environment and overcome disruptions. Restructuring describes changes to the supply chain after disruption to make it as good or better than it was previously. Learning capability is the ability to learn how to deal with risks for effective accumulation of experience to prevent problems in the future. A system of SCRes enablers in three classes with a total of 15 enablers was finally identified, as shown in Table 1.

Table 1. Identified enablers of SCRes.

Categories	Enablers	Code	Reference Source
Proactive	Risk management culture	R1	Liu et al. (2021) [21], Aggarwal & Srivastava (2019) [37]
	Product diversity	R2	Liu et al. (2021) [21]
	Redundancy	R3	Ivanov and Sokolov (2013) [38], Yang and Hsu (2018) [39]
	Social capital	R4	Kumar & Anbanandam (2020) [34], Akgün and Keskin (2014) [40], Bhattacharjya (2018) [41]
	Trust and collaboration	R5	Kumar & Anbanandam (2020) [34], Scholten et al. (2014) [42], Singh et al. (2018) [43]
Reactive	Information sharing	R6	Aggarwal & Srivastava (2019) [37], Urciuoli et al. (2014) [44], Dubey et al. (2018) [45]
	Visibility	R7	Scholten et al. (2014) [42], Ivanov and Sokolov (2013) [38], Dubey et al. (2018) [45]
	Robustness and agility	R8	Yang and Hsu (2018) [39], Brandon-Jones et al. (2014) [46], Gunessee et al. (2018) [47],
	Velocity	R9	Kwak et al. (2018) [48], Scholten et al. (2019) [49],
	Interoperability	R10	Sheffi & Rice (2005) [50]
Restorative	Logistics support	R11	Fan & Lu (2020) [51]
	IT application (including big data analytics, blockchain technology)	R12	Shin & Park (2019) [52], Min (2019) [53]
	Resource configuration	R13	Ali & Gölgeci (2019) [5]
	Restructuring	R14	Ali & Gölgeci (2019) [5]
	Learning capability	R15	Liu et al. (2021) [21], Aslam et al. (2020) [54]

Previous studies used a variety of analysis tools, as listed in Table 2.

Table 2. Related studies using approximate research methods.

Authors	Purpose	Approach	Number of Enabler
Pavlov et al. (2018) [55]	Supply chain resilience assessments are extended by incorporating ripple effect and structure reconfiguration.	Hybrid Fuzzy Probabilistic Approach	30 factors
Rashidi & Cullinane (2019) [56]	A comparison of sustainable supplier selection.	Fuzzy Data Envelopment Analysis (FDEA), Fuzzy TOPSIS (FTOPSIS)	21 factors
Fan & Lu (2020) [51]	Constructing a supply chain resilience evaluation index system from the five dimensions of supply chain prediction ability, adaptability, response ability, recovery ability, and learning ability.	Interpretive Structural Modelling (ISM), Entropy weight-TOPSIS	16 factors
Das et al. (2021) [57]	Analyzing factors that affected the supply chain networks with the onset of COVID-19.	Analytic Hierarchy Process (AHP), Decision-Making Trial and Evaluation Laboratory (DEMATEL)	11 factors
Zhang et al. (2021) [58]	To identify the most supply chain-resilient company suitable for the customized preferences of partner firms in the context of the Chinese supply chain framework during the COVID-19 pandemic.	Fuzzy Analytical Hierarchy Process (FAHP), Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (fTOPSIS), Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), and Evaluation Based on Distance from Average Solution (EDA)	15 factors
Magableh & Mistarihi (2022) [59]	Analyzing the impact of COVID-19 on SCs and enable organizations to prioritize solutions based on their relative importance.	Analytic Network Process (ANP), Technique for Order Preference by Similarity to Ideal Solution framework (TOPSIS)	20 factors
Yazdi et al. (2022) [60]	Transportation service provider selection under uncertainty.	Multiple Criteria Decision-Analysis (MCDA): the Best-Worst Method (BWM) and Multi-Attributive Border Approximation Area Comparison (MABAC) methods are used to rank resilience-related CSFs for transportation service providers in uncertain environments using Hesitant Fuzzy Sets (HFS).	20 factors
Aggarwal & Srivastava (2019) [37]	To explore the phenomenon of collaborative resilience through in-depth case study research in India.	Grey-based DEMATEL	8 factors
Agarwal & Seth (2021) [61]	To identify the barriers influencing supply chain resilience and examine the inter relationships between them.	Total Interpretive Structural Modelling (TISM), Cross-Impact Matrix Multiplication Applied to Classification (MICMAC)	11 barriers
Liu et al. (2021) [21]	Exploring the influencing factors of cross-border e-commerce supply chain resilience (CBSCR), so as to further enhance the competitiveness of global supply chain and ensure the safe operation of cross-border e-commerce supply chain.	Fuzzy DEMATEL-ISM	12 factors with 36 secondary factors

2.2. DEMATEL—ISM Method

The step-wise process of the DEMATEL–ISM integration method is described below:

1. First, the influence relationships between the factors were evaluated by experts, and the resulting data were used to form the direct-relation matrix X of DEMATEL;
2. The matrix X was normalized with the maximum value of the sum of the rows of the matrix X as the normalized base to form a normalized direct-relation matrix N;
3. According to the following formula, the total-relation matrix T was obtained from the normalized direct-relation matrix N, where I is the Identity matrix, and −1 indicates the inverse matrix of the matrix (I-N):

$$T = N(I - N)^{-1} \tag{1}$$

1. According to the following formula, the total-relation matrix T was converted to the initial reachability matrix. The threshold λ can be set based on knowledge or experience, and here was set to:

$$\mathrm{k}_{ij} = \begin{cases} 1, \ t_{ij} \geq \lambda \\ 0, \ t_{ij} < \lambda \end{cases} \tag{2}$$

2. Identity Matrix I was added to the initial reachability matrix via Boolean algebra algorithms to obtain the reachability matrix;
3. Determination of the factors in the reachability set, the antecedent set, and the intersection set of these two sets;
4. When the intersection set C(i) is equal to the reachability set R(i)—that is, C(i) = R(i) ∩ Q(i) = R(i)—the factor is expressed as a first-level factor. Those factors are then removed from the sets, and this process is repeated until all layers of factors are completed.

2.3. Definition of Cloud Model

The cloud model can describe the randomness and fuzziness of qualitative concepts and can realize uncertain transformations between qualitative concepts and quantitative evaluation. This transformation model describes the certainty between qualitative concepts and quantitative expression. [41].

In this model, assume *U* is a quantification field of numerical representation and C is a qualitative concept on *U*. While μ: $U \rightarrow$ [0,1], $\forall$x $\in$ *U*, x $\rightarrow$ μ(x), the quantitative numerical value represents a degree of certainty for a qualitative concept *C*, that μ(x) $\in$ [0, 1] is a random number with a stable uniformity. The distribution of x on theory field *U* is called the cloud, namely C(X), and X is a set of quantitative numerical value of x, which satisfies:

$$\mu(\mathrm{x}) = \exp\left(-\frac{(x_i - Ex)^2}{2En_i'^2}\right) \tag{3}$$

where $\mathrm{x} \sim N\left(Ex,\ En'^2\right)$, $and\ En' \sim N\left(En,\ He^2\right)$.

The cloud is composed of n ordered pairs (x_i, μ_i). The expectation *Ex* is the center of the cloud droplets, which reflects the size of the mean. The entropy *En* represents the validity domain of U, which embodies the ambiguity. The hyperentropy He shows the degree of dispersion of the qualitative concept and corresponds to the thickness of the cloud droplets. The cloud model features are shown in Figure 1.

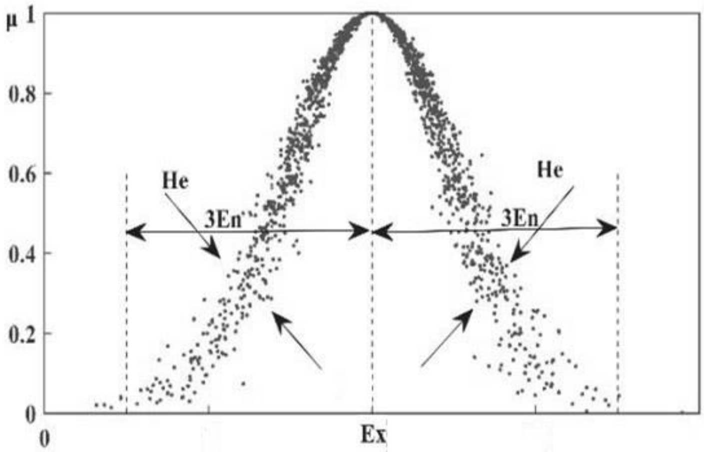

Figure 1. Critical parameters of the cloud model.

2.4. Standard Cloud

A standard cloud was established to reveal the degree of impact of qualitative parameters. The degree of impact was divided into five levels of full, higher, middle, low, and none. The digital characteristics of the cloud can be evaluated according to the following Equation (4) [62]:

$$\begin{cases} Ex_i = \frac{(d_i^{min}+d_i^{max})}{2} \\ En = \frac{(d_{max}-d_{\min})}{6} \\ He = k \end{cases} \tag{4}$$

where k is a constant that is usually assigned a value of 0.5 [63].

Table 3 presents the results of the linguistic terms, value intervals, and corresponding digital characteristics.

Table 3. Linguistic terms, value intervals, and Ex, En, and He values.

Degree of Impact	Linguistic Terms	Value Interval	Ex	En	He
None	0	[0, 0.8]	0.4	0.133	0.5
Low	1	[0.8, 1.6]	1.2	0.133	0.5
Middle	2	[1.6, 2.4]	2	0.133	0.5
Higher	3	[2.4, 3.2]	2.8	0.133	0.5
Full	4	[3.2, 4]	3.7	0.133	0.5

The horizontal axis represents the evaluated range of uncertainty, and the vertical axis represents the membership degree. The membership functions are shown in Figure 2.

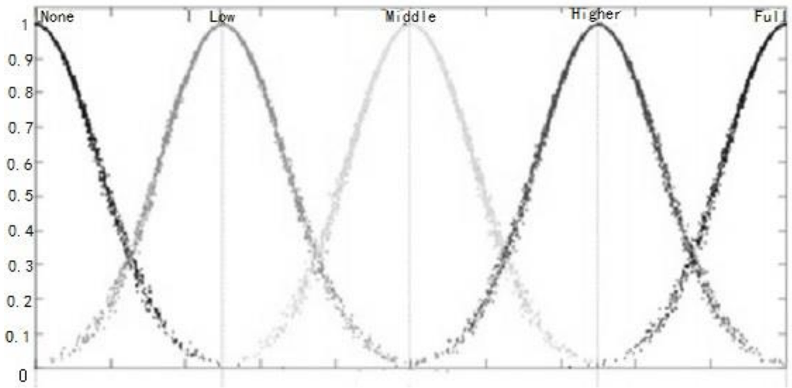

Figure 2. The membership functions of the linguistic terms.

2.5. Backward Cloud Generator

For a given specific value, it is possible to generate the digital characteristics using a backward cloud generator (BCG; as shown in Figure 3b).

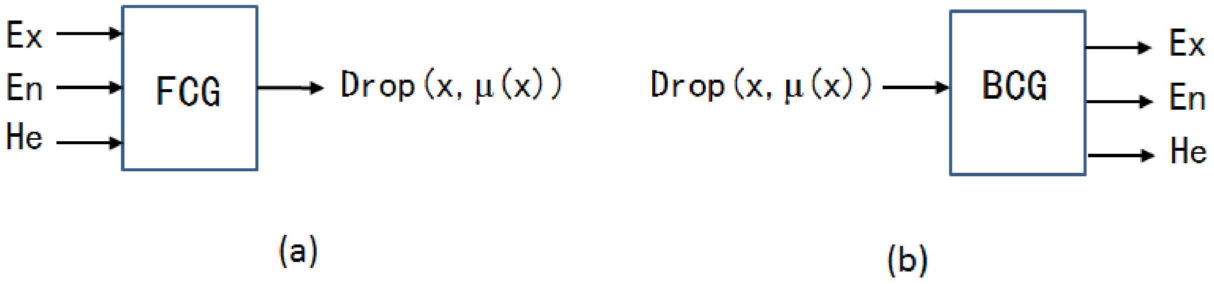

Figure 3. Two types of cloud generators: (**a**) forward cloud generator (FCG), (**b**) backward cloud generator (BCG).

According to cloud droplets, mapping from qualitative to quantitative can generate the digital characteristics (*Ex*, *En*, *He*) of a cloud by BCG, according to the Equation (5):

$$\begin{cases} Ex = \frac{1}{n}\sum_{i=1}^{n} x_i,\ (i = 1, 2, \cdots, n) \\ En = \sqrt{\frac{\pi}{2}}E(|x - Ex|) = \frac{1}{n}\sqrt{\frac{\pi}{2}}\sum_{i=1}^{n}|x_i - Ex| \\ He = \sqrt{D(X) - En^2} \\ = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - Ex)^2 - En^2} \\ = \sqrt{S^2 - En^2} \end{cases} \tag{5}$$

3. Methodology

3.1. Similarity Measure Based on Numerical Characteristics

The LICM (Cloud Model-Based Similarity Comparison Method, LICM) [64] represents a CM with a three-dimensional vector composed of numerical features. A similarity measure defined by the angle-containing cosine of these vectors is commonly used, where v_1 and v_2 are two 3D-vectors, with numerical characteristics respective to C_1 (Ex^1, En^1, He^1) and C_2 (Ex^2, En^2, He^2). The similarity measure of these two vectors is defined by the angle cosine, according to the following Equation (3):

$$\mathrm{sim}(C_1,\ C_2) = \cos v_1 \cdot v_2 = \frac{v_1 \cdot v_2}{|v_1||v_2|}, \tag{6}$$

The cloud generated by the backward cloud generator can then be compared with the standard cloud, and the cloud with the maximum similarity is expressed as the closest evaluation value. This can then be converted into corresponding linguistic terms to obtain the direct-relation matrix of DEMATEL. Implementation of DEMATEL operations is performed to obtain the total-relation matrix.

3.2. The Flow of Cloud Model-DEMATEL–ISM

The complete implementation process flow of Cloud model-DEMATEL–ISM is shown in Figure 4.

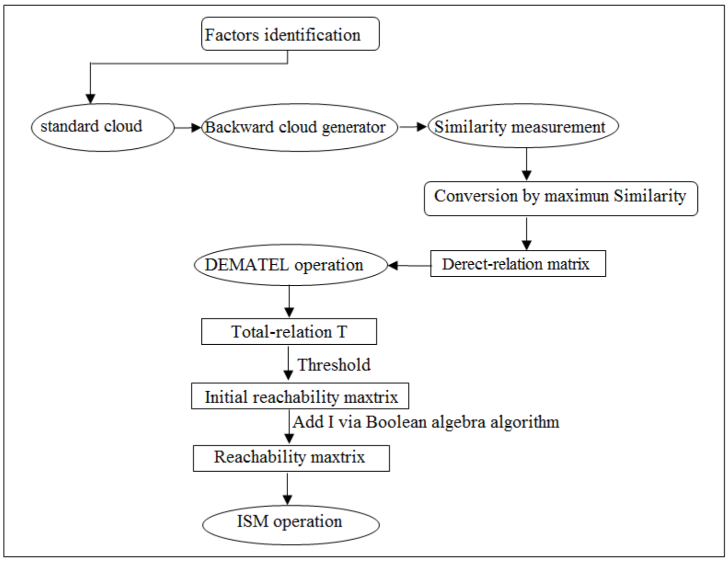

Figure 4. Process flow of cloud DEMATEL−ISM.

4. Analysis

Based on related previous studies, enablers for SCRes were classified into three categories of proactive, reactive, and restorative enablers, for a total of 15 enablers, as listed in Table 1. The new energy vehicle industry in China was selected as the object of study. A total of 38 industry experts who manage and implement supply chain management in this industry and 22 experts from colleges who teach and study supply chain management were invited to evaluate the mutual influence of the set of 15 enablers for SCRes (according to five levels). A total of 48 valid responses were obtained, with 30 respondents from the industry and 18 respondents from colleges. The status of the survey sample is shown in Table 4.

Table 4. The status of the survey sample.

Position in the Organization	Seniority	Years of Experience	Number of People
Manager	<2	>5	3
	2–5	5–10	4
		>10	11
Director	<2	<10	1
		>10	2
	>2	<10	2
		>10	5
VP or above	<2	<20	1
	>2	>20	1
Assistant professor	<5	<5	3
Associate professor	5–10	5–10	2
	>10	>10	9
Professor	>15	>15	4

The standard cloud was calculated, according to formula (4) and Table 3. The valid responses were used to generate the digital characteristics (Ex, En, He) by BCG, according to formula (5). The results are shown in Table 5.

Each cloud was compared with the standard cloud using a similarity measure by LICM method, as presented in Formula (6). The maximum similarity is expressed as the closest evaluation value, and then converted into corresponding linguistic terms to obtain the direct-relation matrix of DEMATEL. The results are shown in Table 6.

Table 5. The digital characteristics of the direct-relation matrix.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
R1	0	(1.432,0.838,0.347)	(1.696,0.983,0.765)	(0.317,0.188,0.265)	(2.124,0.798,0.387)	(1.546,0.768,0.472)	(1.432,0.838,0.347)	(0.882,0.737,0.639)	(1.546,0.768,0.472)	(1.382,0.965,0.269)	(0.536,0.471,0.257)	(0.483,0.626,0.378)	(2.218,0.358,0.378)	(0.372,0.185,0.176)	(0.934,0.658,0.236)
R2	(0.575,0.198,0.528)	0	(0.934,0.658,0.236)	(0.439,0.798,0.238)	(0.413,0.768,0.223)	(0.448,0.382,0.202)	(0.533,0.247,0.183)	(0.271,0.692,0.132)	(0.882,0.737,0.639)	(0.439,0.798,0.238)	(0.317,0.188,0.265)	(0.536,0.471,0.257)	(0.483,0.626,0.378)	(0.575,0.198,0.528)	(0.413,0.768,0.223)
R3	(0,448,0.382,0.202)	(0.533,0.247,0.183)	0	(0.575,0.198,0.528)	(0.317,0,188,0.265)	(0.483,0.626,0.378)	(0.483,0.626,0.378)	(0.575,0.1980.525)	(1.546,0.768,0.472)	(0.439,0.798,0.238)	(0.413,0.768,0.223)	(0.317,0.188,0.265)	((0.533,0.247,0.183)	(0.882,0.737,0.639)	(0.533,0.247,0.183)
R4	(0.317,0.188,0.265)	(0.536,0.471,0.257)	(0.317,0.188,0,265)	0	(2.218,0.358,0.378)	(0.536,0.471,0.257)	(0.536,0.471,0.257)	(0.448,0.382,0.202)	(0.448,0.382,0.202)	(0.533,0.247,0.183)	(1.546,0.768,0.472)	(0.536,0.471,0.257)	(0.483,0.626,0.378)	(1.546,0.768,0.472)	(0.483,0.625,0.378)
R5	(2.218,0.358,0.378)	(0.483,0.626,0.378)	(0,536,0.471,0.257)	(0.439,0.798,0.238)	0	(2.892,0.495,0.428)	(0.934,0.658,0.236)	(1.696,0.983,0.765)	(1.432,0.838,0.347)	(2.124,0.798,0.387)	(0.533,0.247,0.183)	(0.483,0.626,0.378)	(0.536,0.471,0.257)	(2.892,0.495,0.428)	(0.536,0.471,0.257)
R6	(0.439,0.798,0.238)	(1.546,0.768,0.472)	(0.483,0.626,0.378)	(0.317,0.188,0.265)	(0.271,0.692,0.132)	0	(1.546,0.768,0.472)	(1.814,0.782,0.632)	(0.575,0.198,0.528)	(0.882,0.737,0.639)	(0.483,0.626,0.378)	(0.575,0.198,0.528)	(0.882,0.737,0.639)	(0.439,0.798,0.238)	(0.882,0.787,0.639)
R7	(0.533,0.247,0.183)	(0.575,0.198,0.528)	(0.575,0.198,0.528)	(0.536,0.471,0.257)	(1.546,0.768,0.472)	(0.429,0.382,0.192)	0	(1.382,0.965,0.269)	(0.934,0.658,0.236)	(0.483,0.626,0.378)	(0.536,0.471,0.257)	(0.439,0.798,0.238)	(1.546,0.768,0.472)	(0.317,0.188,0.265)	(0.439,0.798,0.238)
R8	(0.271,0.692,0.132)	(0.483,0.626,0.378)	(0.882,0.737,0.639)	(0.483,0.626,0.378)	(0.575,0.198,0.528)	(0.575,0.198,0.528)	(0.533,0.247,0.183)	0	(1.546,0.768,0.472)	(0.934,0.658,0.236)	(0.317,0.188,0.265)	(0.533,0.247,0.183)	(0.575,0.198,0.528)	(0.536,0.471,0.257)	(0.575,0.198,0.528)
R9	(0.536,0.471,0.257)	(0.271,0.692,0.132)	(1.546,0.768,0.472)	(0.533,0.247,0.183)	(0.533,0.247,0.183)	(0.448,0.382,0.2.2)	(0.536,0.471,0.257)	(0.882,0.737,0.639)	0	(0.536,0.471,0.257)	(0.439,0.798,0.238)	(0.271,0.692,0.132)	(0.483,0.626,0.378)	(0.483,0.626,0.378)	(0.575,0.198,0.528)
R10	(0.483,0.626,0.378)	(0.533,0.247,0.183)	(0.533,0.247,0.183)	(0.483,0.626,0.378)	(2.432,0.936,0.687)	(0.882,0.737,0.639)	(0.483,0.626,0.378)	(1.546,0.768,0.472)	(0.317,0.188,0.265)	0	(0.575,0.198,0.528)	(0.536,0.471,0.257)	(0.271,0.692,0.132)	(0.533,0.247,0.183)	(0.483,0.626,0.378)
R11	(0.413,0.768,0.223)	(0.448,0.382,0.202)	(0.271,0.692,0.132)	(0.934,0.658,0.236)	(1.382,0.965,0.269)	(0.372,0.185,0.176)	(1.382,0.965,0.269)	(0.533,0.247,0.183)	(0.439,0.798,0.238)	(1.382,0.965,0.269)	0	(0.483,0.626,0.378)	(0.533,0.247,0.183)	(1.814,0.782,0.632)	(0.271,0.692,0,132)
R12	(0.372,0.185,0.176)	(0.413,0.768,0.223)	(1.432,0.838,0.347)	(0.413,0.768,0.223)	(0.483,0.626,0.378)	(1.696,0.983,0.765)	(3.176,0.913,0.653)	(0.934,0.658,0.236)	(0.575,0.198,0.528)	(0.533,0.247,0.183)	(0.533,0.247,0.183)	0	(0.448,0.382,0.202)	(0.934,0.658,0.236)	(0.533,0.247,0.183)
R13	(0.533,0.247,0.183)	(1.814,0.782,0.632)	(2.588,0.575,0.336)	(0.448,0.382,0.202)	(0.533,0.247,0.183)	(0.271,0.692,0.132)	(0.317,0.188,0.265)	(1.382,0.965,0.269)	(1.432,0.838,0.347)	(0.536,0.471,0.257)	(0.271,0.692,0.132)	(0.271,0.692,0.132)	0	(0.317,0.188,0.265)	\(0.448,0.382,0.202)
R14	(1.382,0.965,0.268)	(0.533,0.247,0.183)	(0.372,0.185,0.176)	(0.533,0.247,0.183)	(0.533,0.247,0.183)	(0.533,0.247,0.183)	(0.439,0.798,0.238)	(0.317,0.188,0.265)	(0.533,0.247,0.183)	(0.483,0.626,0.378)	(0.372,0.185,0.176)	(0.575,0.198,0.528)	(1.382,0.965,0.269)	0	(0.413,0.768,0.223)
R15	(2.432,0.936,0.687)	(0.271,0.692,0.132)	(0.575,0.198,0.528)	(0.271,0.692,0.132)	(0.483,0.626,0.378)	(0.448,0.382,0.202)	(0.575,0.198,0.528)	(1.546,0.768,0.472)	(0.271,0.692,0.132)	(1.546,0.768,0.472)	(0.533,0.247,0.183)	(0.448,0.382,0.202)	(0.439,0.798,0.238)	(1.546,0.768,0.472)	0

Table 6. Corresponding linguistic terms/maximum similarity.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15
R1	0	1/0.972	2/0.988	0/0.799	2/0.987	1/0.960	1/0.972	1/0.976	1/0.960	1/0.981	0/0.888	0/0.957	2/0.939	0/0.760	1/0.986
R2	0/0.685	0	1/0.986	0/0.978	0/0.979	0/0.880	0/0.730	0/0.976	1/0.976	0/0.978	0/0.799	0/0.888	0/0.957	0/0.685	0/0.979
R3	0/0.880	0/0.730	0	0/0.685	0/0.799	0/0.957	0/0.967	0/0.685	1/0.960	0/0.978	0/0.979	0/0.799	0/0.730	1/0.976	0/0.880
R4	0/0.799	0/0.888	0/0.799	0	2/0.939	0/0.888	0/0.888	0/0.880	0/0.880	0/0.730	1/0.960	0/0.888	0/0.957	1/0.960	0/0.957
R5	2/0.939	0/0.957	0/0.888	0/0.978	0	3/0.977	1/0.986	2/0.988	1/0.972	2/0.987	0/0.730	0/0.957	0/0.888	3/0.977	0/0.888
R6	0/0.978	1/0.960	0/0.957	0/0.799	0/0.976	0	1/0.960	2/0.990	0/0.685	1/0.976	0/0.957	0/0.685	1/0.976	0/0.978	1/0.976
R7	0/0.730	0/0.685	0/0.685	0/0.888	1/0.960	1/0.972	0	1/0.981	1/0.986	0/0.957	0/0.888	0/0.978	1/0.960	0/0.799	0/0.978
R8	0/0.976	0/0.957	1/0.976	0/0.957	0/0.685	0/0.685	0/0.730	0	1/0.960	1/0.986	0/0.799	0/0.730	0/0.685	0/0.888	0/0.685
R9	0/0.888	0/0.976	1/0.960	0/0.730	0/0.730	0/0.880	0/0.888	1/0.976	0	0/0.888	0/0.978	0/0.976	0/0.957	0/0.957	0/0.685
R10	0/0.957	0/0.730	0/0.730	0/0.957	2/0.989	1/0.976	0/0.957	1/0.960	0/0.799	0	0/0.685	0/0.888	0/0.976	0/0.730	0/0.957
R11	0/0.979	0/0.880	0/0.976	1/0.986	1/0.981	0/0.760	1/0.981	0/0.730	0/0.978	1/0.981	0	0/0.957	0/0.730	2/0.990	0/0.976
R12	0/0.760	0/0.979	1/0.972	0/0.979	0/0.957	2/0.988	3/0.994	1/0.986	0/0.685	0/0.730	0/0.730	0	0/0.880	1/0.986	0/0.730
R13	0/0.730	2/0.990	3/0.986	0/0.880	0/0.730	0/0.976	0/0.799	1/0.981	1/0.972	0/0.888	0/0.976	0/0.976	0	0/0.799	0/0.880
R14	1/0.981	0/0.730	0/0.760	0/0.730	0/0.730	0/0.730	0/0.978	0/0.799	0/0.730	0/0.957	0/0.760	0/0.685	1/0.981	0	0/0.979
R15	2/0.989	0/0.976	0/0.685	0/0.976	0/0.957	0/0.880	0/0.685	1/0.960	0/0.976	1/0.960	0/0.730	0/0.880	0/0.978	1/0.960	0

The total-relation matrix was calculated according to the computational steps of DEMATEL, and the results are presented in Table 7.

Table 7. Total-relation matrix.

0.04	0.11	0.21	0	0.17	0.13	0.1	0.16	0.14	0.13	0	0	0.17	0.06	0.08
0	0	0.08	0	0	0	0	0.01	0.08	0	0	0	0	0.01	0
0.01	0	0.01	0	0	0	0	0.01	0.07	0	0	0	0.01	0.07	0
0.03	0.01	0.01	0.01	0.16	0.04	0.02	0.04	0.02	0.04	0.07	0	0.02	0.12	0.01
0.17	0.04	0.07	0	0.06	0.26	0.11	0.24	0.13	0.2	0	0	0.07	0.23	0.03
0.01	0.03	0.04	0	0.02	0.02	0.08	0.17	0.03	0.09	0	0	0.08	0.01	0.07
0.01	0.02	0.04	0	0.08	0.09	0.01	0.11	0.1	0.03	0	0	0.08	0.02	0.01
0	0.07	0.08	0	0.01	0.01	0	0.01	0.08	0.07	0	0	0	0.01	0
0	0.01	0.08	0	0	0	0	0.07	0.01	0.01	0	0	0	0.01	0
0.03	0.01	0.02	0	0.15	0.11	0.02	0.12	0.03	0.04	0	0	0.02	0.03	0.01
0.03	0.01	0.01	0.07	0.11	0.04	0.08	0.04	0.02	0.09	0.01	0	0.03	0.17	0
0.01	0.01	0.09	0	0.02	0.17	0.23	0.12	0.04	0.03	0	0	0.04	0.08	0.01
0	0.15	0.24	0	0	0	0	0.08	0.11	0.01	0	0	0	0.02	0
0.07	0.02	0.03	0	0.01	0.01	0.01	0.02	0.02	0.01	0	0	0.08	0.01	0.01
0.16	0.02	0.04	0	0.04	0.03	0.02	0.11	0.03	0.1	0	0	0.03	0.08	0.01

The criterion used for the threshold was that values must not be equal to 0 or 1, giving the initial reachability matrix. The initial reachability matrix is added to the identify matrix I via Boolean algebra algorithm to obtain the reachability matrix, and the result is shown in Table 8.

Table 8. The reachability matrix.

1	1	1	0	1	1	1	1	1	1	0	0	1	1	1
0	1	1	0	0	0	0	1	1	0	0	0	0	1	0
1	0	1	0	0	0	0	1	1	0	0	0	1	1	0
1	1	1	1	1	1	1	1	1	1	1	0	1	1	0
1	1	1	0	1	1	1	1	1	1	0	0	1	1	1
1	1	1	0	1	1	1	1	1	1	0	0	1	1	1
1	1	1	0	1	1	1	1	1	1	0	0	1	1	1
0	1	1	0	1	1	0	1	1	1	0	0	0	1	0
0	1	1	0	0	0	0	1	1	1	0	0	0	1	0
1	1	1	0	1	1	1	1	1	1	0	0	1	0	1
1	1	1	1	1	1	1	1	1	1	1	0	1	1	0
1	1	1	0	1	1	1	1	1	1	0	1	1	1	1
0	1	1	0	0	0	0	1	1	1	0	0	1	1	0
1	1	1	0	1	1	1	1	1	1	0	0	1	1	1
1	1	1	0	1	1	1	1	1	1	0	0	1	1	1

A hierarchical structure analysis of ISM was performed according to the reachability matrix, and the results are shown in Table 9.

Table 9. The level partition of ISM analysis.

Factors	Reachability Set	Antecedent Set	R ∩ A = R	Layer
R1	1,2,3,5,6,7,8,9,10,13,14,15	1,3,4,5,6,7,10,11,12,14,15		
2	2,3,8,9,14	1,2,4,5,6,7,8,9,10,11,12,13,14,15		
3	1,3,8,9,13,14	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	Y	
4	1,2,3,4,5,6,7,8,9,10,11,13,14	4,11		
5	1,2,3,5,6,7,8,9,10,13,14,15	1,4,5,6,7,8,10,11,12,14,15		
6	1,2,3,5,6,7,8,9,10,13,14,15	1,4,5,6,7,8,10,11,12,14,15		
7	1,2,3,5,6,7,8,9,10,13,14,15	1,4,5,6,7,10,11,12,14,15		I
8	2,3,5,6,8,9,10,14	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	Y	
9	2,3,8,9,10,13,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	Y	
10	1,2,3,5,6,7,8,9,10,13,15	1,4,5,6,7,8,9,10,11,12,13,14,15		
11	1,2,3,4,5,6,7,8,9,10,11,13,14	4,11		
12	1,2,3,5,6,7,8,9,10,12,13,14,15	12		
13	2,3,8,9,10,13,14,15	1,3,4,5,6,7,10,11,12,13,14,15		
14	1,2,3,5,6,7,8,9,10,13,14,15	1,2,3,4,5,6,7,8,9,11,12,13,14,15		
15	1,2,3,5,6,7,8,9,10,13,14,15	1,5,6,7,10,12,14,15		

Table 9. *Cont.*

Factors	Reachability Set	Antecedent Set	R ∩ A = R	Layer
R1	1,2,5,6,7,10,13,14,15	1,4,5,7,10,11,15		II
2	2,14	1,2,4,5,6,7,10,11,12,13,14,15	Y	
4	1,2,4,5,6,7,10,11,13,14	4,11		
5	1,2,5,6,7,10,13,14,15	1,4,5,6,7,10,11,12,15		
6	2,5,6,7,10,13,14	1,4,5,6,7,10,11,12		
7	1,2,5,6,7,10,13,14	1,4,5,6,7,10,11,12,13,14		
10	1,2,5,6,7,10,13	1,4,5,6,7,10,11,12,13,14,15		
11	1,2,4,5,6,7,10,11,13,14	4,11		
12	2,5,6,7,10,12,13,14	12		
13	2,10,13,14	1,4,5,6,7,10,11,12,13,14,15		
14	2,10,13,14	1,2,4,5,6,7,11,12,13,14,15		
15	1,2,5,10,13,14,15	1,5,15		
R1	1,5,6,7,10,13,14,15	1,4,5,7,10,11,15		III
4	1,4,5,6,7,10,11,13,14	4,11		
5	1,5,6,7,10,13,14,15	1,4,5,6,7,10,11,12,15		
6	5,6,7,10,13,14	1,4,5,6,7,10,11,12		
7	1,5,6,7,10,13,14	1,4,5,6,7,10,11,12,13,14	Y	
10	1,5,6,7,10,13	1,4,5,6,7,10,11,12,13,14,15	Y	
11	1,4,5,6,7,10,11,13,14	4,11		
12	5,6,7,10,12,13,14	12		
13	10,13,14	1,4,5,6,7,10,11,12,13,14,15	Y	
14	10,13,14	1,4,5,6,7,11,12,13,14,15		
15	1,5,10,13,14,15	1,5,15		
R1	1,5,6,14,15	1,4,5,11,15		IV
4	1,4,5,6,11,14	4,11		
5	1,5,6,14,15	1,4,5,6,11,12,15		
6	5,6,14	1,4,5,6,11,12		
11	1,4,5,11,14	4,11		
12	5,12,14	12		
14	14	1,4,5,6,11,12,14,15	Y	
15	1,5,14,15	1,5,15		
R1	1,5,6,15	1,4,5,11,15		V
4	1,4,5,6,11	4,11		
5	1,5,6,15	1,4,5,6,11,12,15	Y	
6	5,6	1,4,5,6,11,12	Y	
11	1,4,5,6,11	4,11		
12	5,6,12	12		
15	1,5,15	1,5,15	Y	
R1	1	1,4,11	Y	VI
4	1,4,11	4,11		
11	1,4,11	4,11		
12	12	12	Y	
R4	4,11	4,11	Y	VII
11	4,11	4,11	Y	

5. Results

As shown in Figure 5, the hierarchy structure was determined by applying the cloud model-DEMATEL–ISM approach. Social capital (R4) and restructuring (R11) occupy layer VII (bottom layer); risk management culture (R1) and information technology (R12) occupy layer VI; trust and collaboration (R5), information sharing (R6), and learning capability (R15) occupy layer V; restructuring (R14) occupies level IV; visibility (R7), interoperability (R10), and resource configuration (R13) occupy layer III; product diversity (R2) occupies level II; and redundancy (R3), robustness and agility (R8), and velocity (R9) occupy level I (top layer). Based on the inner influence relationships, social capital (R4) and restructuring (R11) lead to the flow of risk management culture (R1). Risk management culture (R1) leads to the flow of trust and collaboration (R5), information sharing (R6), and learning capability (R15). Information technology (R12) leads to the flow of trust and collaboration (R5) and information sharing (R6). Trust and collaboration (R5), information sharing (R6), and learning capability (R15) lead to the flow of logistics support (R11). Logistics support (R11) leads to the flow of visibility (R7), interoperability (R10), and resource configuration (R13), and these enablers lead to the flow of product diversity (R2). Product diversity (R2) leads to the flow of redundancy (R3), robustness and agility (R8), and velocity (R9).

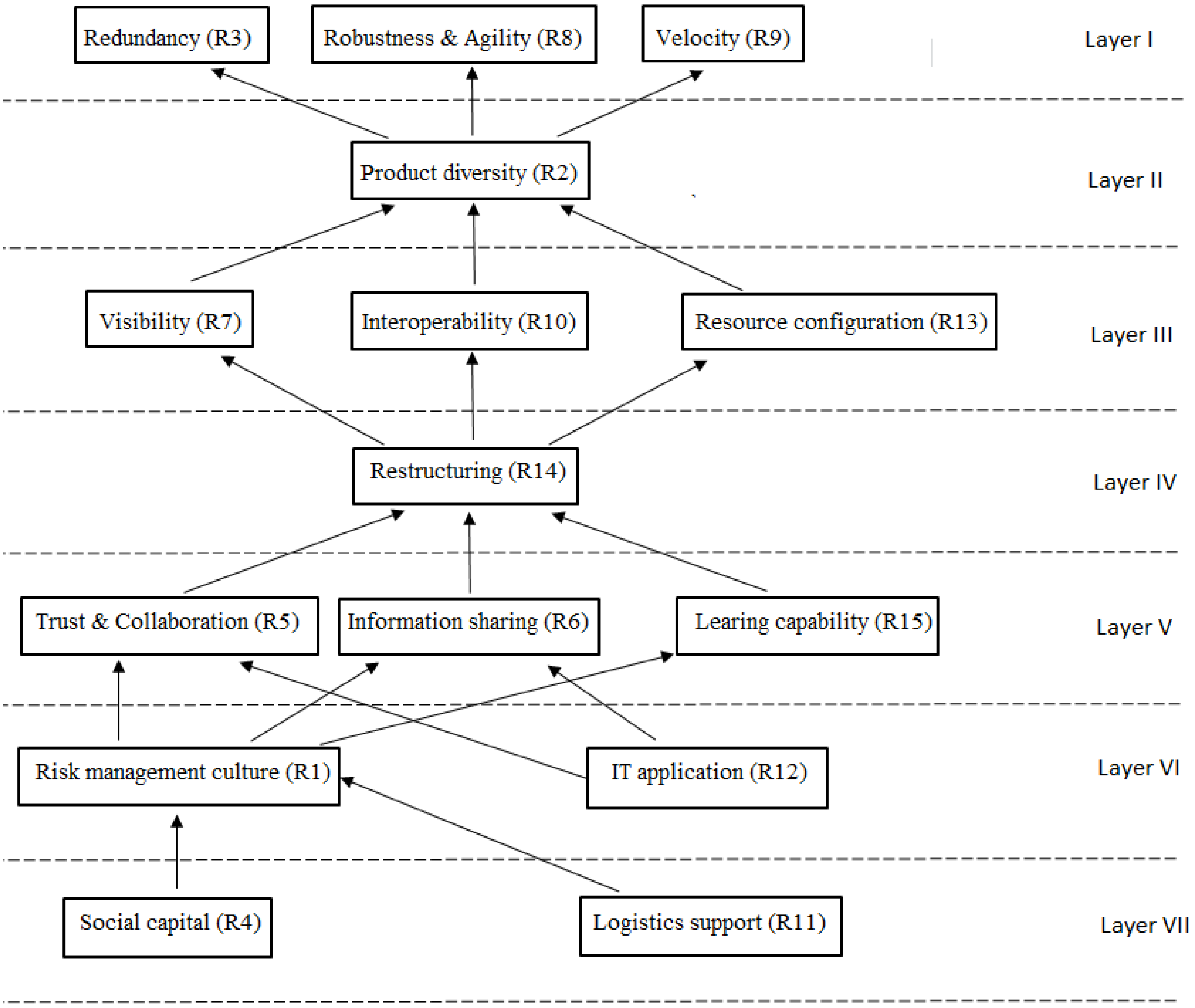

Figure 5. The hierarchical structure and the interactional relationship.

Cross-impact matrix multiplication applied to classification (MICMAC) can be used to analyze the reachability matrix. Define t_{ij} as elements of the i^{th} row and j^{th} column in the final reachability matrix, and then calculate the total effect and total affected. The total effect (A_i) is equal to: $A_i = \sum_{j=1}^{n} t_{ij}$. The total affected ($Aed_j$) is equal to: $Aed_j = \sum_{i=1}^{n} t_{ij}$. Then, the driving force of factor i is equal to $A_i - Aed_i$, and its dependence force is equal to $A_i + Aed_i$. Factors were classified based on their located cluster on the driver-dependence matrix diagram and were classified into four types of factors as: (1) Autonomous factors, located in quadrant I (lower left portion of the graph). These factors are less connected to the rest of the system and have little impact on it. They are autonomous and excluded. (2) Dependent factors, located in quadrant II (lower right portion of the graph). These factors are very sensitive to changes in the driver and linkage factors and serve as the output factor of the whole system. They can serve as an indicator for evaluating the effectiveness of the whole system. (3) Relay factors, located in quadrant III (upper right portion of the graph). These factors have high influence and high dependence. They not only influence other factors, but are also greatly influenced by other factors. Any action on these factors will impact others in the graph and feed back to the acting factor, thereby amplifying or supporting the original effect. These factors are unstable and have linkage or relay characteristics. (4) Influence factors, located in quadrant IV (upper left portion of the graph). These factors have high influence and low dependence. They are very influential and relatively uninfluenced by other factors in the system. These factors are the critical factors, as they can markedly affect the entire system depending on how effectively they are controlled.

The result is shown in Figure 6:

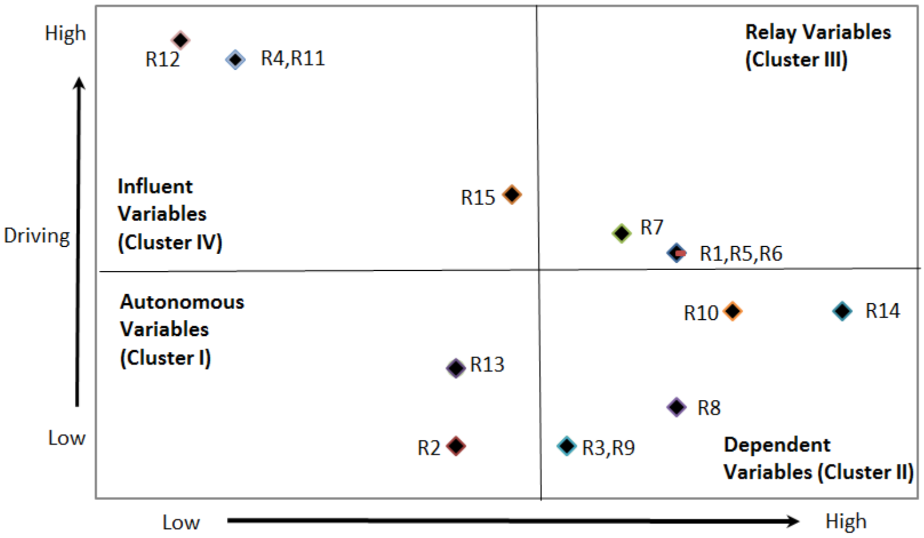

Figure 6. Driver-dependence matrix diagram of quality enablers of SCQM.

6. Discussion

Based on Figures 5 and 6, we can conclude that the most fundamental and important enablers to strengthen supply chain resilience are social capital and logistics support. This means companies should focus on intangible resources derived from the company's inter-organizational relationships. In particular, logistics support is required to facilitate the distribution and transportation of goods for companies (as found previously by Jung & Son, 2016 [65]). Then, a company's own risk management culture determines the ability to give early warning, plan, evaluate, avoid, and control risks before a crisis occurs. IT application (e. g., big data analytics, blockchain technology) can link and respond to unpredictable changes and disruptions across functions and organizations. Additionally, a company must have internalized capability, including trust and collaboration (as found previously by Liu & Dou, 2021 [21]). This is required for supply chain entities to trust and cooperate effectively to mutual benefit. Information sharing allows the collective of members in a supply chain to utilize their available information resources and share these resources effectively. Learning capability is the ability to deal with risks and effectively accumulate experience to prevent problems in the future. Restructuring refers to the efforts to rebuild the supply chain after disruption to make it as good or better than it was previously. A company must have conceptual abilities such as visibility, allowing control of the whole SC operation process, from end-to-end, in order to reduce risks. A rapid response involves built-in interoperability with interchangeable standard processes so that people familiar with the operation can work effectively at multiple locations. Resource configuration is the ability to redirect internal and external resources to adapt to a changing business environment and overcome disruptions. The technical ability of a company includes redundancy and product diversity, such as the maintenance of excess equipment or capacity and alternative complementarity of multiple products to disperse supply chain risks. Robustness and agility describe resistance to adverse conditions, the ability to evolve constantly, the ability to sense dynamic market changes, and the ability to react quickly to meet clients' needs. Velocity is the speed of reaction to a disruption. These enablers have interactional relationships, which must also be considered. Implementation in the order of the hierarchy of enablers and attention to the mutual interaction relationships of enablers can most effectively enhance supply chain resilience.

The level partition of ISM analysis and the driver-dependence matrix diagram can guide managerial decisions and provide insight into the importance and attributes of enablers of SCRes. Social capital (R4), logistics support (R11), IT application (R12), and learning capability (R15) are in cluster IV of the driver-dependence matrix diagram. These enablers have a strong driving force and weak dependence force, and are considered influent variables. These enablers lie in the lower portion of the hierarchy, suggesting that strategies should emphasize and effectively manage these enablers to enhance SCRes. Risk management culture (R1), trust and collaboration (R5), information sharing (R6) (R5 and R6 were found previously Agarwal & Seth, 2021 [61]), and visibility (R7) are classified as relay variables. These enablers are in the middle portion of the hierarchy, and depend on the lower portion. In particular, an organization should focus on the trust and collaboration of suppliers, as found previously by Jung & Son, 2016 [65]. Product diversity (R2) and resource configuration (R13) are classified as autonomous variables. These enablers lie in the upper portion of the hierarchy and have a weak driving force and weak dependence force. The other enablers are classified as dependent variables. When a company understands the interaction among the enablers, the hierarchy of enablers, and the driving force and dependence of the enablers, it can effectively strengthen SCRes.

7. Conclusions

In this study, we compiled 15 items of enablers of SCRes based on previous studies. We explored the hierarchical structure and the interactional relationships between the enablers of SCRes by the cloud model-DEMATEL–ISM method, with increased analysis accuracy. The results of analysis reveal the complex relationships between enablers that contribute to SCRes. The results showed that social capital and restructuring are on the bottom layer; risk management culture and information technology are on layer VI; trust and collaboration, information sharing, and learning capability occupy layer V; restructuring occupies layer IV; visibility, interoperability and resource configuration occupy layer III; and product diversity occupies layer II; and redundancy, robustness and agility, and velocity occupy layer I. The interactional relationships of the enablers were also determined. MICMAC analysis was used to analyze the driving force and dependence force of enablers, and then the enablers were classified into four clusters. This classification can reveal interactions among enablers, allowing the management of a company to focus on enablers with a high driving force and thus effectively strengthen SCRes. Based on these, we suggest that companies trying to improve SCRes should focus on enablers in the base layer and with a high driving force, such as social capital, restructuring, risk management culture, information technology application, trust and collaboration, information sharing, and learning capability.

7.1. Implications

Several theoretical implications can be drawn from this study. The cloud model-DEMATEL–ISM method effectively analyzed the hierarchical structure and the interactional relationships between the enablers of SCRes. MICMAC was used for analysis of the driving and dependence forces of enablers. The results can help companies strengthen supply chain resilience.

7.2. Limitations

Although this study makes novel contributions by the application of the cloud model-DEMATEL–ISM method, there are limitations to this work. The number of surveys was limited, and the analysis scope of this work was limited to the new energy vehicle industry in China. Future work should use structural equation modeling (SEM) to test overall model validity and to assess specific aspects of SCRes. Moreover, the multi-level hierarchical structure of the enablers and the levels of relevance deserve further exploration. In addition, the analysis scope should expand to investigate other regions and countries and specific industries.

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