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RESEARCH ARTICLE

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Blockchain-based efficient communication for food supply chain industry: Transparency and traceability analysis for sustainable business

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Summary

In recent years, blockchain (BC) networks have expanded to a broad spectrum of fields. They have garnered significant attention due to their feature of creating secure private and public networks in a decentralized manner. The traditional FSC fails to meet the customer requirements of quality, safety, reliability, transparency, and traceability. This paper proposes a novel 3-stage methodology using principal component analysis (PCA), total iterative structural modeling (TISM), and Matrice d'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) analysis to develop an integrated BC with the food supply chain (FSC). The existing literature was surveyed and industry experts' opinion was gathered and various critical success factors (CSF) were identified which are associated with FSC and BC. The data collected from experts were then evaluated for data consistency and dimension reduction through PCA. The dimensionally reduced data set was analyzed by TISM and MICMAC analysis. TISM and MICMAC analysis categorizes the enabler factors according to their hierarchical level and is used to label or distinguish between dependence and driving power. The integrated methodology found nine CSFs, namely, transparent system, fraud detect, inventory management with tracking, scalability, secure system, cost reduction, safe and quality food, customer satisfaction, and government regulations, which are the main drivers for the FSC business. The paper integrates information technology, Blockchain, with operation management, supply chain. The proposed model overcomes the limitation associated with FSC and will motivate the academia and industry to adopt and achieve efficient and effective goals in this field of FSC.

KEYWORDS

blockchain, food supply chain, MICMAC, PCA, TISM

1 | INTRODUCTION

Food safety and management significantly affects public health and has become an essential subject of concern in both print and digital media around the globe. The media have exposed the various food scandals such as the China milk scandal in 2008, the U.K. horsemeat in 2013,[1] and India's immense "food theft" scandal.[2] All these cases have a common cause, that is, lack of transparency and ineffective batch arrangement, leading to lack of traceability in the FSC. The activities involved in the FSC system are agriculture, harvesting, warehousing, processing, transportation, and delivery. Most of the traditional FSC System purely tracks and stores deliveries and orders, without providing the features like transparency, traceability and auditability. Therefore, establishing an accurate and useful traceability system will undoubtedly improve food quality and safety. According to Costa et al.,[3] there is an urgent necessity of traceability in the supply chain industry, mainly in the agri-food industry. Some giant associations like IBM, Walmart JD.com, and Tsinghua University have established an alliance for Food Safety using BC, a coordinated effort to address security issues in managing nourishment supply chains in China.[4] The traditional supply chain architecture uses a centralized system which is operated and maintained by a third-party, which may suffer from single node attack or have a high risk of data tampering and information disclosure. BC provides a decisive outcome and effective performance in the FSC process. In this technology, we have blocks—each having a specific identity (address) and information. The information stored in each block cannot be erased, changed, or updated, and a new block gets created when the information in any block is modified. The FSC becomes effective and efficient using a unique feature of BC.[5] BC creates a trusted network among suppliers and eliminates the need for the middle man[6]; secondly, another supplier in the chain can also track the product. Rayes and Salam[7] suggested that this makes them highly efficient with high transmission speed, reduces the cost, and enhances the quality significantly as compared with the traditional FSC.

In FSC, the demand of the product is random and seasonal; therefore, for the smooth flow of product from a vendor to customer, it is essential for the end-user to track the product reliability and avoid unnecessary shortage. India is an agrarian country which has a diverse culture and eating habits. Each state has its primary crop and products are procured from farmers across the country. These products are stored and processed at a different location before they are integrated into the FSC. The system should adhere to privacy, security, smart contract, scalability, traceability, and trackability for a reliable FSC. In the present time, the customers are curious about the products they consume. Through BC, the customer will be able to possess information, right from placement of an order to authenticity of products. BC will also allow them to be confident about the impact of the product and its effect on the environment along with working condition, quality and other essential information related to products. After reviewing works of literature, based on BC technology and FSC, the following research gaps were found,

- Few studies have focused on analyzing various factors that affect the BC integration in the existing FSC,
- BC is an emerging technology and relatively naïve, limited research is available in identifying the enablers of the BC and understanding how they are inter-related with each other.

1.1 | Motivations

The primary motivation of this paper is to develop an integrated BC with the existing FSC, which is efficient, robust, smart, and trackable, using PCA, TISM, and MICMAC analysis. BC methodology is still in its nascent stage, and model for adaption to existing FSC is limited. The proposed model overcomes the limitation associated with FSC and will motivate the academia and industry to adopt and achieve efficient and effective goals in this field of FSC.

1.2 | Research contributions

Following are the research contributions of this paper.

- To identify potential enablers for BC adoption in FSC.
- To develop PCA-TISM-MICMAC analysis for finding the driver.
- Establish relationship enablers and their inter-dependencies established using combined TISM and MIMAC methodology.

- Finally, highlight the open issues and research challenges in the adoption of BC in FSC industry.

1.3 | Organization

The paper is organized into six sections. Section 1 is introduction followed by Section 2 which reviews the literature in the area of BC and FSC and explains CSF, Section 3 discusses the research methodology, Section 4 presents the result and its interpretation, and Section 5 gives the conclusion. Lastly, Section 6 discusses the limitations and future scope of the research.

2 | LITERATURE REVIEW

The literature review has two sections: first, it elaborates about the current issues in FSC, and, second, it focuses on Blockchain.

2.1 | Current food supply chain and food protection

The main key factors of FSC management (FSCM) are food quality and food safety. Food companies use the hazard analysis and critical control points (HACCP) technique to solve the safety problems in the FSC. IoT is a system of interrelated computing devices, mechanical and digital machines, which connects all the things with internet with the help of different IoT devices like WSN, GPS, RFID, and GIS. These devices are composed of different type of networks such as sensor network, high-speed network, and reliable public network.[8] RFID is radio frequency-based, non-contact identification communication technology, that facilitates multiple product/material automatic recognition moving at the variable speed at the same time, under poor environment without labor-intensive intervention. RFID can also protect, label, and manage data of specific product or material. RFID has a full-scale application in the area of logistic, supply chain, production, quality management, inventory, and warehouse management owing to its various benefits, such as cost, durability, sustainability, ease of mass production, recyclability and ease of operation. Researchers have considered the application of IOT based RFID GIS and GPS in FSC management. The simulation model developed by Sari[9] shows that RIFD technology is beneficial in the supply chain when lead time is longer due to uncertainty in the product demand. The simulation model is presented by Ustundag and Tanyas[10] which estimates the gain in the performance in terms of security, trackability, accuracy, transparency, and increase in production by using the RIFD-based system in a supply chain. A decision support system for real-time agri-food monitoring is proposed by Wang et al.[11] which appraises the vendor/customer about the remaining values and self-life time of the agri-product. Tse et al.[12] presented a model which can track and trace the quality, security, and other factors associated with vegetable production supply chain.

2.2 | Blockchain technology

BC is a new rising technology which has drawn the attention of researchers from different domains. The first BC application in the market was bitcoin and distributed electronic cash system that defined further how BC could be used in other fields like voting and IPR.[13–16] Kosba et al.[17] offered a decentralized smart contract framework named Hawk, dissimilar to other existing decentralized BC frameworks in which all the changes are perceivable obviously on the BC.[18–21] “Hawk” does not store the money-related exchange on the framework; therefore, conceals value-based security from the general visibility.[22–24] Bruce[25] has proposed peer to peer cryptocurrency scheme with mini-BC. Bruce's research defines the “proof chain,” “account Tree,” and “mini-BC.” Also, it describes how all these mechanisms work collectively to construct a new structure that can provide both security and integrity. Apart from that, this new system also has many other benefits such as quicker transactions, less amount of fee, faster network synchronization, high-level traffic support, and extra block space for routine messages.

Abeyratne and Monfared[26] describe the benefit of BC technology in the manufacturing supply chain in their paper. McConaghy[27] introduced BigchainDB, which is a combination of the distributed database (DB) with BC features like decentralized, immutability, creation, and movement of digital assets. BC application consists of numerous smart contracts. A smart contract is a computer program or a transaction protocol, which intends to execute automatically and control or document legally relevant events and actions according to the terms of a contract. A smart contract is widely used in virtual currency sector.

BC is an emerging technology, and there are some hindrances in the BC application. For example, current transaction capacity of BC is limited to seven transactions per second, while sensor data are transferred continuously on a massive scale.[25] The rise of BC could potentially foster innovative changes and facilitate assert movement across the world in seconds. In BC, asserts represented digitally and transferred in an immutable and decentralized mode. Distributed networks of computers are maintained through BC to keep track of all the transactions, and the entire system works jointly.[28] After each transition, authentication and verification are processed by the mining of the nodes, and a block is generated, which is appended to the existing BC. This process of authentication, verification, and unique identity generation helps to address the concerns stated by the World Health Organization (WHO2017). According to WHO, harmful bacteria, viruses, parasites, and chemical substance are present in unsafe food which causes harm to humans and, nearly 1 out of 10 people fall sick due to contaminated food. BC can be used for food traceability in the FSC, that is, with digital tracking food can be traced from farm to fork.

Some big companies have already adopted BC technology to expand their business. One of the world's largest logistic management company, FedEx is using BC to track high-value cargos.[29] The big players of food sectors have also adopted the growing technology. Burger King, Russia,[30] has launched its cryptocurrency token which is known as whopper coin on the wave's platform. Walmart[31] has introduced a tracking system using BC to trace the food globally through the supply chain. Leeway Hertz[32] created end to end solutions to construct the enterprise-grade BC application. MasterCard[33] had added 30 BC patents in their account. Overstock[34] accepts the Bitcoin payment on

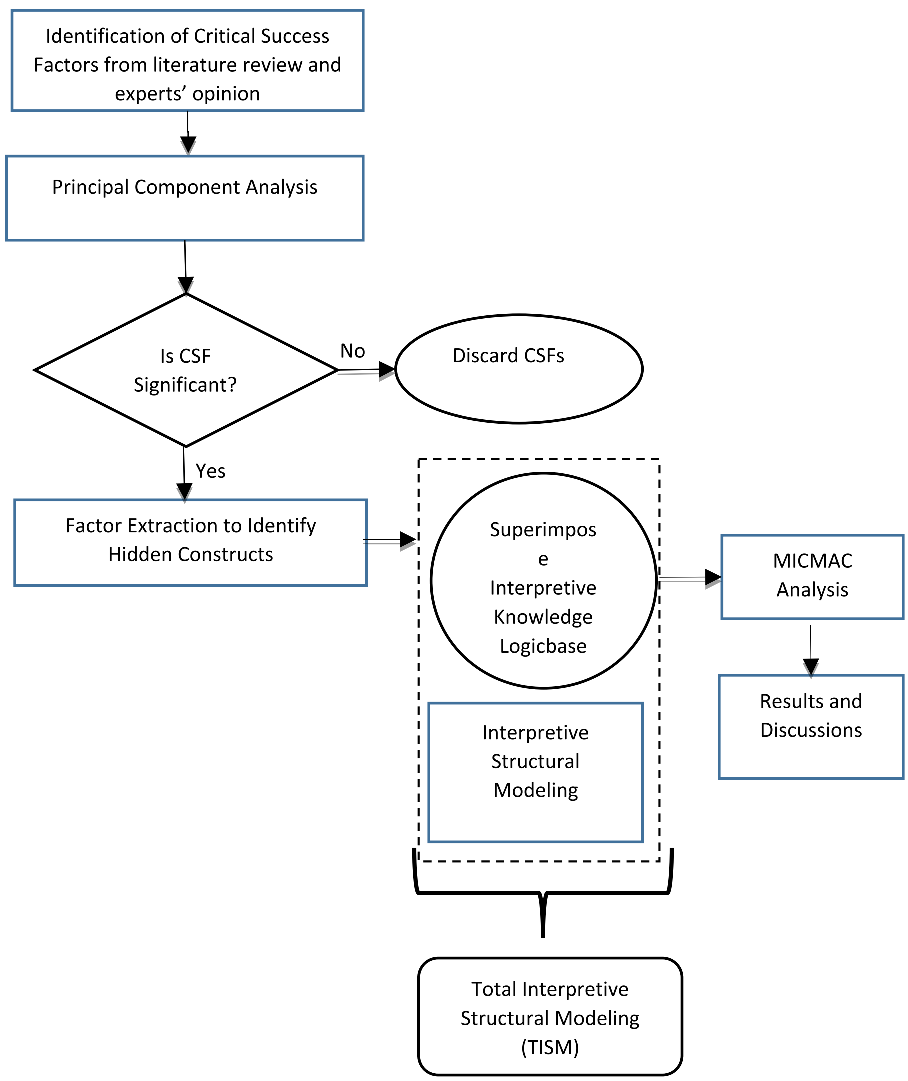

FIGURE 1 The research methodology

their website. Bank of America has a patent of shared networks of ATMs powered by BC technology.[35] Huawei Technologies[36] launched BC service all over the world wherein users can create, deploy, and manage the BC application on Huawei Cloud. By using the Hyper ledger BC creator tool, IBM[37] is helping the organizations to create their own distributed ledger and smart contract systems. Different companies that deal with logistics have a partnership to increase efficiency and lower the cost-by deploying BC in their supply chain channel.[38] Since 2014, Microsoft

TABLE 1 Critical success factors for BC implementation in the food sector

S. No.	Critical success factors	Description	References
1	Real-time transparency	BC is a type of distributed ledger. The network participates in the BC network shares the same records as opposed to individual copies.	Wüst and Gervais[43] and Yiannas[44]
2	Fraud detection	As the data are stored in all the ledgers that are distributed so it is difficult to hack the system and difficult to make the unauthorized changes	Benchoufi, Porcher, and Philippe[45]
3	Real-time traceability	It is tough to change and delete the data once it is added in the BC. Multiple locations store the data and ledgers are immutable as a result product of a particular company can be tracked back in the supply chain	Tian[46] and Yuan et al.[47]
4	Reduce paperwork	All the transactions and orders are placed online, and an e-invoice is generated against the supplier.	Soosay et al.[48]
5	Provenance tracking	From birth to end, the node cannot be modified and are traceable.	Leng et al.[49] and Tian[50]
6	Risk reduction	Transparency in the data, it reduces multiple risks.	Shrier et al.[51]
7	Scalable	Offering an almost unlimited database that can be accessed from multiple touchpoints from around the world.	Crosby et al.[6] and Karame[52]
8	Reduce the cost	You do not require the third party as outsiders or middle people to make ensures because it does not make a difference on the off chance that you can believe your exchanging accomplice.	Crosby et al.[6] and Shae and Tsai[53]
9	Security	Transactions are to be agreed upon before they are logged. After an exchange is accepted, it is encrypted and connected to the previous transaction. User can be identified by providing encryption keys or contact can be guaranteed to escape others to sight the figures.	Khatri[35]
10	Safe and quality food	Due to provenance tracking, it is easy to maintain the quality and safety of the food items.	Khatri[35] and Tse et al.[12]
11	Customer satisfaction	Customer will be aware of where their food is coming from, and these aspects will increase customer trust.	Costa et al.[3] and Chakrabarti and Chaudhuri[54]
12	Government regulations	Great governance standards are necessary instruments required for another industry to develop and thrive.	Regattieri, Gamberi, and Manzini[55]
13	Reduce human errors	Programmed exchanges and controls diminish the creation of mistakes by people.	Lakhani and Iansiti[56]
14	Improve inventory management	Trust is expanded because of permanent recordkeeping and by verification of the information by numerous hubs.	Verma et al.[57] and Elizaveta[58]
15	Improve the quality	No modification can be done, as it is simultaneously updated the data in each node.	Bocek et al.[59] and Kamath[60]
16	Error-prone transactions	Cryptographically encrypted transactions make it secure.	Lemieux[61]
17	Eliminate the duplication	Verified by multiple nodes and no modification in the existing nodes	Fujimura et al.[62]
18	Disintermediation	No single party has authoritative control	Wüst and Gervai[43] and Mattila[63]
19	Provide secure riot digital market	By using IoT tools and BC technology, it will increase the security business in the market with less risk.	Huh, Cho, and Kim[64] and Tian[65]

has started accepting the bitcoin payment on its website. Tanwar et al.[39] has proposed a blockchain based smart energy trading scheme for efficient mechanism for secure energy. Khan et al.[40] presented a security solution for blockchain and log-based Public Key Infrastructure (PKI). Martin et al.[41] research highlight the application of fog computing in domain of blockchain. Akram et al.[42] and Gupta et al.[43] discuss the recent advancement in blockchain and its challenges.

2.3 | Critical success factors theory

CSF theory acts as an instrument to measure the performance of any association and to achieve the company's goals. According to Rockhart and Bullen[39] the CSF method is a means for identifying essential elements of success. It was originally developed to align information technology planning with the strategic direction of an organization, thus focusing on the restricted areas in which acceptable results with effective economic performance can be achieved. CSF is the main area where things go right for the business to grow and for managers to obtain the goals.[40] Many researchers have done their study using the CSFs theory, including the FSC.[41,42] However, the research on the application of CSF theory for the implementation of BC technology to address the issues in the food sector till date is limited.

At a national level and international level, food sector plays a significant role in socio-economic development of any society.[66] Reducing the cost and growing effectiveness of the advanced technology inspires to adopt the BC technology. This technology also ensures transport logistics for perishable products. In the integration of BC and FSC, CSF plays a vital role in identifying the key drivers of BC in the FSC.[67]

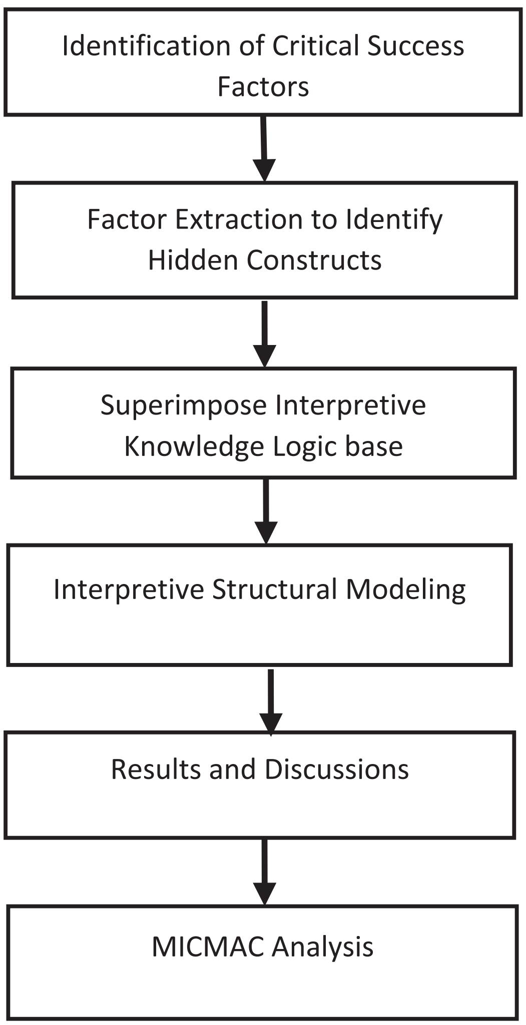

FIGURE 2 TISM methodology steps

3 | RESEARCH METHODOLOGY

This section elucidates the methodology of identifying the factors from the published literature and based on one to one discussion with industry experts. These factors are essential to integrate BC with FSC followed by PCA, TISM to study and establish the relationship between the CSFs BC in the food sector. The proposed research has been depicted in

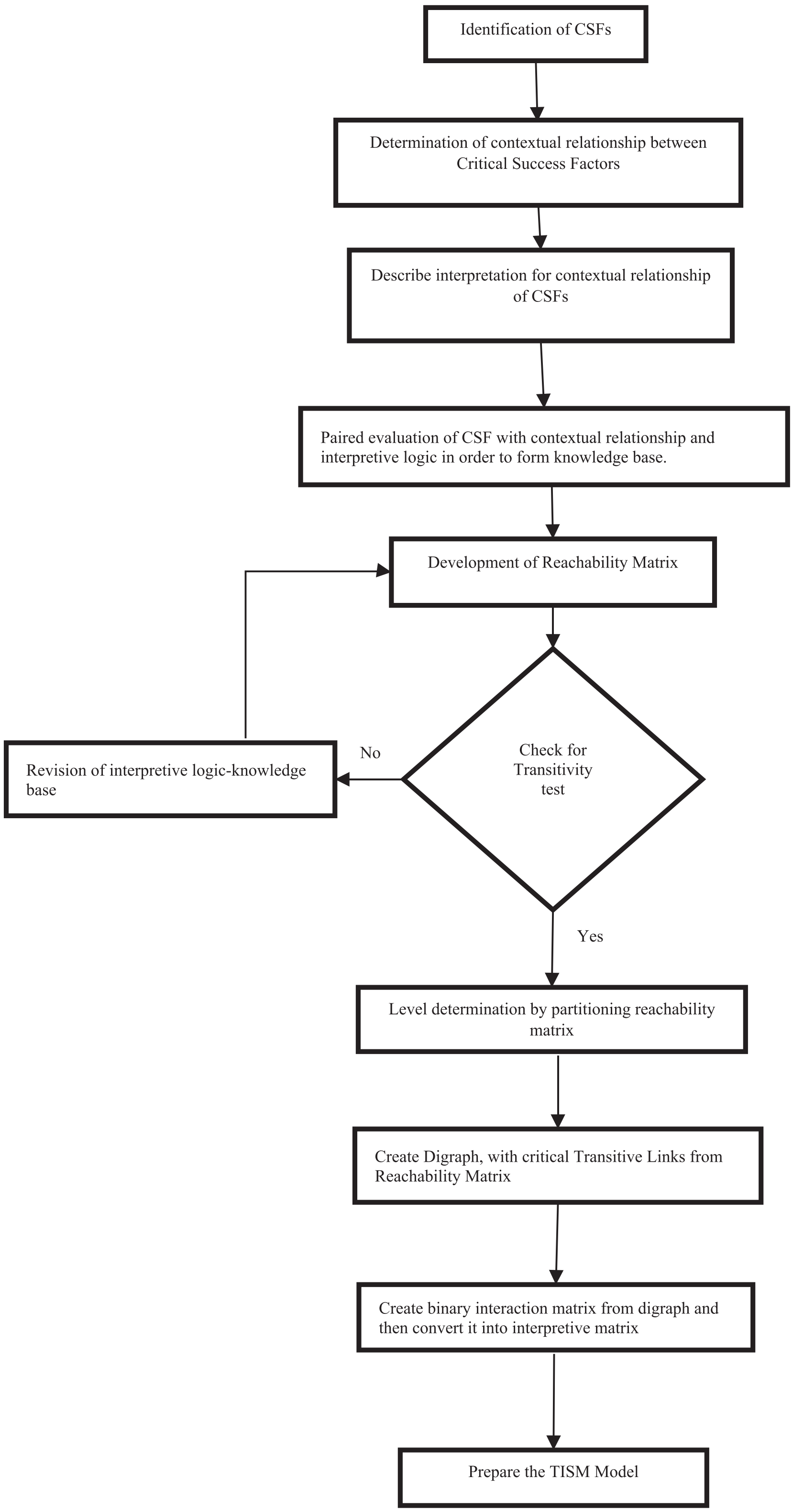

FIGURE 3 Flow chart TISM

Figure 1 and elaborated below. A total number of 19 CSFs have been identified from the research papers and given in Table 1. The purpose of this paper is to provide a framework to analyze and establish a link between the CSF of BC in the food sector. Details steps are elaborated below,

I. Identification of CSFs for BC-based FSC system from the literature survey and Industry experts.
II. Principal component analysis: PCA is a multivariate data analysis used for data reduction. PCA uses an orthogonal transformation to convert a set of criteria into a set of values of linearly uncorrelated variables called principal components. PCA method is comprehensively studied in the literature and in-depth facts.
III. Questionnaire-based survey: The final questionnaires with reduced CSF (9) obtained after performing PCA to measure the impact of identified CSFs of BC-based FSC was sent to industry experts and researchers in the fields of manufacturing logistic, storage of food, and other perishable products (India).
IV. TISM is a structural modeling technique which arranges the variables in a systematic hierarchy.[58] The core steps of both models are similar. The only difference is that TISM provides the clarification of all the links in each node, and second enhancement holds selected transitive links that have expressive interpretation. ISM interprets only the nodes, whereas TISM interprets both nodes and links in the digraph. Thus, the interpretation of the interactive relationships represented by directed links for the identified factors/variables relatively lacks in the ISM approach and thus may distort the process of decision making. Moreover, in ISM all transitive links are eliminated, whereas TISM can have some important transitive links giving a better explanatory framework. It answers all the three critical questions of theory building, that is, what, how, and why. However, in ISM, all the transitive links are dropped and makes the TISM model descriptive.[68] The TISM methodology steps have been shown in Figure 2, and the TISM flow chart is given in Figure 3.

4 | RESULTS AND ANALYSIS

Nineteen BC variables have been identified from the literature and in consultation with expert opinion. It has been further factorized into nine (principal factors) using PCA. These nine factors are (CSF1) transparent system, (CSF2) fraud detect, (CSF3) inventory management with tracking, (CSF4) scalability, (CSF5) secure system, (CSF6) cost reduction,

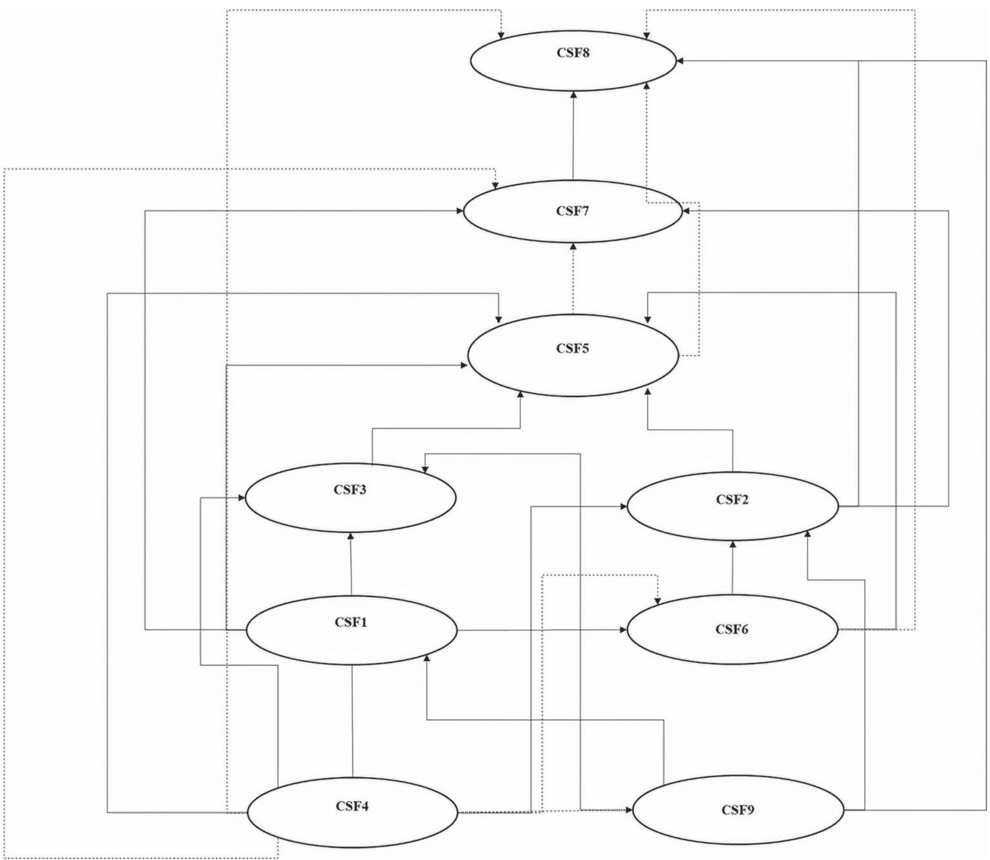

FIGURE 4 Digraph with significant transitive links

(CSF7) safe and quality food, (CSF8) customer satisfaction, and (CSF9) government regulations. TISM and MICMAC analyses categorize the enablers factors according to their hierarchical level, used to label or distinguish between dependence and driving power, which has been shown in Figures 4 and 5. The computation of values against each process and their explanation has been given in Section 4 (Tables 2–8).

4.1 | PCA-dimension reduction using factor analysis

A large set of factors (elaborated in Table 1) affect the BC design; therefore, the efficacy and contribution of factors needs to be evaluated. Google Doc Questioner was prepared, and experts from academia and industry were asked the

FIGURE 5 TISM-based model for CSFs of BC-based FSC

TABLE 2 KMO and Bartlett's test

Kaiser-Meyer-Olkin measure of sampling adequacy		**0.545**
Bartlett's test of sphericity	Approx. chi-square	174.859
	df	171
	Sig.	0.404

fill the form through email. They were asked to rank each criterion on the Likert Scale of 5 where 1 to 5 where 1 is low and 5 is very high. PCA is used to remove redundant criteria. Further details can be studied from Tayal and Singh,[69] Pandey and Solanki,[70] and Tayal et al.,[71] and correlation matrix of the criteria is obtained.

TABLE 3 Total variance explained and extraction method.

	Initial eigenvalues			Extraction sums of squared loadings		
Component	**Total**	**% of variance**	**Cumulative %**	**Total**	**% of variance**	**Cumulative %**
1	1.818	9.571	9.571	1.818	9.571	9.571
2	1.723	9.070	18.641	1.723	9.070	18.641
3	1.579	8.309	26.950	1.579	8.309	26.950
4	1.470	7.736	34.686	1.470	7.736	34.686
5	1.326	6.976	41.663	1.326	6.976	41.663
6	1.211	6.372	48.035	1.211	6.372	48.035
7	1.141	6.005	54.040	1.141	6.005	54.040
8	1.110	5.842	59.882	1.110	5.842	59.882
9	1.064	5.599	65.481	1.064	5.599	65.481
10	0.964	5.075	70.556			
11	0.861	4.532	75.088			
12	0.807	4.249	79.337			
13	0.741	3.902	83.239			
14	0.717	3.773	87.011			
15	0.640	3.366	90.377			
16	0.539	2.835	93.213			
17	0.503	2.647	95.859			
18	0.428	2.254	98.113			
19	0.358	1.887	100.000			

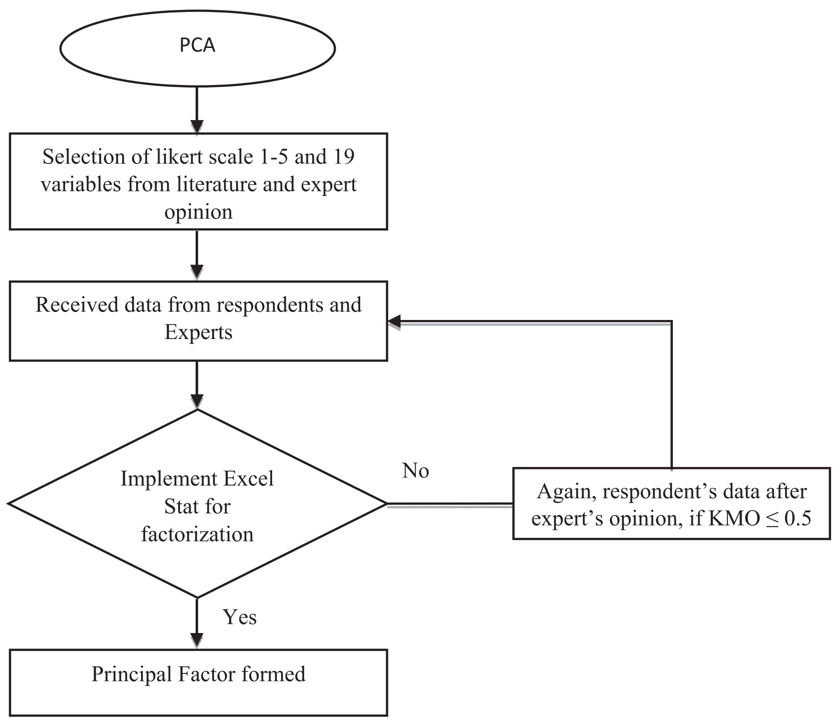

FIGURE 6 PCA flow chart for factorization—nine CSFs

The extraction of factors-PCA is an orthogonal transformation that converts a set of decision criteria matrix into a linearly uncorrelated variable called principal components. The first principal component represents the most significant possible variance (that is, it accounts for as much of the variability in the data as possible), and each succeeding component gives the next most substantial variance and so on.

The resulting vectors are a linear combination of uncorrelated orthogonal basis set. Cayley-Hamilton equation is used to identify eigenvalues and vectors, respectively.[72] Given below is the Cayley-Hamilton equation where λ is the characteristic root (eigenvalue), and Y eigenvector and A correlation matrix, I is the unit matrix. Only those factors are considered for analyzing BC whose eigen values are more than 1.

$$(A - I\lambda)Y = 0$$

SPSS professional tool has been used for data analysis.

Validity Measure: The appropriateness of the data for structure detection has been evaluated using the Bartlett Test of Sphericity (BTS) and Kaiser-Meyer-Olkin (KMO). Table 3.3 presents the test results. Acceptable values of KMO should be high (>0.5) and for BTS should be low (significant level of $p < 0.05$).

Here below is the flow chart for the PCA algorithm (Figure 6).

4.2 | Factor extraction and factor rotation

The dimension reduction or criteria reduction considers the eigenvalues greater than 1. These factors account for more than 65% of the "total variance explained." As shown in Table 3, the first factor accounts for 9.57%, second factor for 9.07%, third factor for 8.3%, fourth factor for 7.736%, fifth factor for 6.96%, sixth factor for 6.37%, seventh factor for 6.00%, eighth factor for 5.84%, and ninth factor for 5.599% of the variance. These nine factors together assess 65.881% of the absolute difference in the information.

4.3 | Factors naming

After performing PCA, nine factors have been identified. Their mapping and naming have been elaborated in Table 4. Table 5 shows the final names of each group, which form the factor for evaluating BC for FSC using TISM and MIC-MAC analysis.

4.4 | The TISM model

A TISM has been used to establish a causal relationship between the factors identified by the experts and represented as an interpretive matrix, thus identifying factors which drive the integrated BC-based FSC.

TABLE 4 Final list of CSFs

Abbreviation	Name of the factor
CSF1	Transparent system
CSF2	Fraud detect
CSF3	Inventory management with provenance tracking and low risk
CSF4	Scalability
CSF5	Secure the system
CSF6	Cost reduction
CSF7	Safe and quality food
CSF8	Customer satisfaction
CSF9	Government regulations

TABLE 5 Mapping of extracted factors and clusters

Criteria		Mapping of extracted factors and clusters								
		Factor1 transparent system	**Factor2 fraud detect**	**Factor 3 inventory management with provenance tracking and low risk**	**Factor4 scalability**	**Factor 5 secure the system**	**Factor 6 cost reduction**	**Factor 7 safe and quality food**	**Factor 8 customer satisfaction**	**Factor9 government regulations**
Cluster1	Real time transparency	**0.446**	−0.083	0.082	0.366	−0.232	0.065	−0.271	0.207	0.017
	Reduce human errors	**0.455**	0.088	−0.105	−0.354	0.295	−0.168	−0.292	−0.048	0.337
Cluster 2	Fraud detect	0.026	**−0.421**	−0.125	−0.284	0.154	0.087	0.064	0.396	0.461
Cluster 3	Reduce the paperwork	−0.053	0.205	**0.569**	0.336	0.31	−0.237	−0.129	0.108	−0.305
	Provenance tracking	−0.134	0.343	**−0.5**	0.091	0.068	−0.332	0.326	0.005	0.013
	Improve inventory management	−0.301	0.236	**0.496**	−0.18	0.14	−0.089	0.003	−0.026	0.381
	Risk reduction	0.247	−0.366	**0.587**	−0.252	0.186	−0.258	0.359	0.258	−0.385
Cluster4	Scalable	−0.305	−0.122	−0.122	**0.428**	0.352	−0.104	0.081	0.073	0.148
	Improve the quality	0.381	0.327	−0.094	**−0.417**	−0.054	0.029	0.19	0.381	−0.25
	Error prone transactions	0.307	0.097	−0.237	**0.503**	−0.239	−0.019	0.211	0.174	0.006
Cluster5	Eliminate the duplication	0.101	0.319	0.329	−0.185	**−0.488**	0.275	0.03	0.026	0.035
	Security	−0.259	−0.184	−0.116	0.105	**−0.402**	0.386	−0.054	0.254	−0.542
Cluster 6	Reduce the cost	0.249	0.124	0.177	0.238	0.316	**0.513**	0.322	0.27	0.203
	Disintermediation	0.076	0.07	−0.08	−0.132	0.378	**0.489**	0.215	−0.318	−0.373
Cluster 7	Safe and quality food	0.05	0.07	0.13	0.149	−0.135	0.11	**0.544**	−0.356	0.396
Cluster 8	Real-time traceability	0.117	−0.095	0.156	0.103	−0.184	−0.242	0.283	0.626	0.111
	Customer satisfaction	−0.375	0.18	0.018	−0.24	−0.083	−0.058	0.109	0.47	−0.217
	Provide secure IoT digital market	−0.069	−0.333	0.176	−0.094	−0.283	−0.133	0.307	−0.499	−0.04
Cluster 9	Government regulations	−0.314	−0.023	−0.019	−0.032	−0.158	0.349	−0.044	0.36	**0.482**

The bold emphases are clusters include the eigenvalue more than 0.4.

The step by step analysis is presented as follows:

Step 1. Recognize and interpret contextual relationships among the variables/CSF: Contextual relationship is established and is measured (as CSF1 influence CSF2). The explanation of each association is essential to deliver an inclusive clarification of the model. The experts have shown that whether CSF1 influences CSF2 or not and if the contextual relation is "yes" then in what way CSF1 influence CSF2 is provided.

Step 2. Construct the final reachability matrix and transitive association: Transitive association/relationship is established based on representation, and final reachability matrix is obtained. For example, if CSF1 influences CSF2 and CSF2 influences CSF3, it means that CSF1 also influences CSF3. The final entries obtained as per transitivity rules are denoted by "*" which has been shown in Table 6.

Step 3. Level partition on reachability matrix: It is the method of ranking different elements at different levels. Partitioning is performed until the degree of each factor is resolved, as shown in Table 4. The antecedent and reachability set is obtained from the reachability matrix. If there are intersecting factors or elements between the two, those factors will occupy the top level. Subsequently, top-level factors are removed and the same is iterated to obtain various levels or ranking.

Step 4. Develop digraph: directed graph or digraph is obtained from the level of elements identified from the reachability matrix. The CSF are arranged graphically where transitive connections are taken in digraph whose translation is important. A chart with vast transitive connections appears in Figure 4. Transitive connections in a digraph are represented by dabbed lines.

Step 5. **Interpretive matrix**: It is a matrix representation of digraph. Significant links and direct links between factors are presented at a glance. A binary interaction matrix is obtained by placing/entering 1 in relevant cells. The interpretive matrix for CSFs of BC-based FSC has been shown in Table 8.

Step 6. Total interpretive structure model: By using the facts from the digraph and interpretive matrix, a TISM model has been developed for CSFs of BC implementing the FSC system. All indicator connections among the CSF are shown using the arrows. The relationship among the CSFs is constructed and displayed with links and model (TISM), as shown in Figure 5. Government regulations (CSF) and provenance tracking (CSF) have the lowest precedence in the hierarchy model of TISM, points towards these factors are the weighty CSFs with the ability to drive all the remaining factors. The highest precedence is given to customer satisfaction (CSF).

CSF8 has minimum driving power and maximum dependence. In this era, lifestyle and food consumption patterns are changing rapidly. Consumers in metros are more sensitive and inquisitive to know about various aspects/information associated with foods that are being delivered, prepared and consumed by an individual. The requirement is of an effective traceability system to regain consumer's lost confidence.

TABLE 6 Final reachability matrix

	CSF1	CSF2	CSF3	CSF4	CSF5	CSF6	CSF7	CSF8	CSF9	Driving power
CSF1	1	1	1	0	1	1	1	1	0	7
CSF2	0	1	0	0	1	0	1	1	0	4
CSF3	0	0	1	1	1	1	0	1	0	5
CSF4	1	1	1	1	1	1*	1*	1*	1*	9
CSF5	0	0	0	0	1	1	1*	1*	1*	5
CSF6	0	1	0	0	1	1	1	1*	1*	6
CSF7	0	0	0	0	0	0	1	1	1*	3
CSF8	0	0	0	0	0	0	0	1	1	2
CSF9	1	1	1	0	0	0	0	1	1	5
Dependence	3	5	4	2	6	5	6	9	6	

Note: asterisk one (1*) entries describe the transitive relationship.

TABLE 7 Partitioning of the reachability matrix (levels)

Critical success factors	Reachability set	Antecedent set	Interaction set	Level
Iteration 1				
CSF1	{1, 2, 3, 5, 6, 7, 8}	{1, 4, 9}	{1}	
CSF2	{2, 5, 7, 8}	{1, 2, 4, 6, 9}	{2}	
CSF3	{3, 5, 6, 8}	{1, 3, 4, 9}	{3}	
CSF4	{1, 2, 3, 4, 5, 6, 7, 8, 9}	{4}	{4}	
CSF5	{5, 6, 7, 8, 9}	{1, 2, 3, 4, 5, 6}	{5, 6}	
CSF6	{2, 5, 6, 7, 8, 9}	{1, 3, 4, 5, 6}	{5, 6}	
CSF7	{7, 8, 9}	{1, 2, 4, 5, 6, 7}	{7}	
CSF8	{8, 9}	{1, 2, 3, 4, 5, 6, 7, 8, 9}	{8, 9}	I
CSF9	{1, 2, 3, 8, 9}	{4, 5, 6, 7, 8, 9}	{8, 9}	
Iteration 2				
CSF1	{1, 2, 3, 5, 6, 7}	{1, 4}	{1}	
CSF2	{2, 5, 7}	{1, 2, 4, 6}	{2}	
CSF3	{3, 5, 6}	{1, 3, 4}	{3}	
CSF4	{1, 2, 3, 4, 5, 6, 7}	{4}	{4}	
CSF5	{5, 6, 7}	{1, 2, 3, 4, 5, 6}	{5, 6}	
CSF6	{2, 5, 6, 7}	{1, 3, 4, 5, 6}	{5, 6}	
CSF7	{7}	{1, 2, 4, 5, 6, 7}	{7}	II
CSF9	{1, 2, 3}	{4, 5, 6, 7}	{}	
Iteration 3				
CSF1	{1, 2, 3, 5, 6}	{1, 4}	{1}	
CSF2	{2, 5}	{1, 2, 4, 6}	{2}	
CSF3	{3, 5, 6}	{1, 3, 4}	{3}	
CSF4	{1, 2, 3, 4, 5, 6}	{4}	{4}	
CSF5	{5, 6}	{1, 2, 3, 4, 5, 6}	{5, 6}	III
CSF6	{2, 5, 6}	{1, 3, 4, 5, 6}	{5, 6}	
CSF9	{1, 2, 3}	{4, 5, 6}	{}	
Iteration 4				
CSF1	{1, 2, 3}	{1, 4}	{1}	
CSF2	{2}	{1, 2, 4}	{2}	IV
CSF3	{3}	{1, 3, 4}	{3}	IV
CSF4	{1, 2, 3}	{4}	{4}	
CSF6	{2}	{1, 3, 4}	{5, 6}	
CSF9	{1, 2, 3}	{4}	{}	
Iteration 5				
CSF1	{1}	{1, 4}	{1}	V
CSF4	{1}	{4}	{4}	
CSF6	{}	{1, 3, 4}	{}	V
CSF9	{1}	{4}	{}	
Iteration 6				
CSF4	{}	{4}	{}	VI
CSF9	{}	{4}	{}	VI

Note: Different iteration referred in italic values in the first column.

TABLE 8 Interpretive matrix for BC-based FSC

	CSF1	CSF2	CSF3	CSF4	CSF5	CSF6	CSF7	CSF8	CSF9
CSF1	--	--	Digitizing the process from end to end	--	Better control of risk leads to transportation management	Hardly data can be manipulated	Food will tell from it came	More recognition and visibility among customer	--
CSF2	--	--	--	--	Moderate risk of food spoilage and frauds	--	Facilitate safe food	Greener technologies, higher outputs	---
CSF3	--	--	--	--	No alteration and duplication	--	---	---	--
CSF4		Reveals its true origin and touchpoints	Digitized decentralized architecture	--	Verified with each node	Indelible ledger with codified rules	Greater scalability	Know each and everything about a product	Every information is in government record
CSF5	--	--	--	--	--	--	Result in good quality food	Increase the trust	--
CSF6	--	Smarter technology means more effective safeguard	--	--	---	--	--	Increase the trust in the associated a food brand	--
CSF7	--	--	--	--	--	--	--	Safe and healthy food	--
CSF8	--	--	--	--	--	--	--	--	--
CSF9	Facilitate the transparency	Impose regulations to control fraudulent activities	Promote the paperless work	--	--	--	--	Involvement of government make the system safe and confident	--

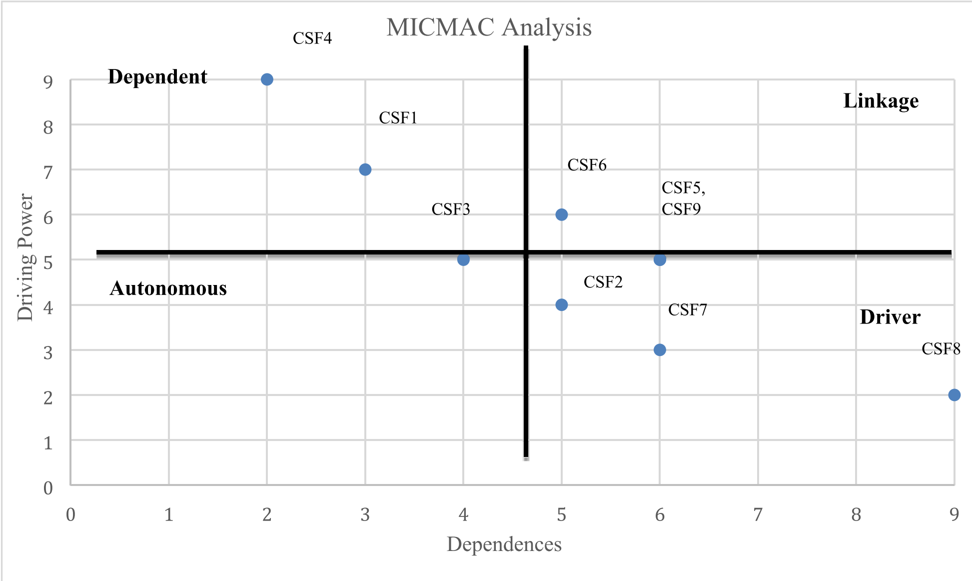

FIGURE 7 MICMAC analysis of BC-based FSC

4.5 | The MICMAC analysis

MICMAC analysis is a cross-impact matrix multiplication applied to classification. MICMAC analysis helps in identifying the critical success parameters based on analyzing the driving power and dependences of the variables.[73,74] MICMAC is an indirect classification method to analyze the scope of each element critically. Simultaneously, it gives some valuable insights about the relative importance and interdependencies among the identified factors.

CSF is classified into four various clusters, as illustrated in Figure 7:

1. Cluster 1: Autonomous variables. In this group, CSF has weak dependence and driving power. This CSF almost does not have any attached links with other CSFs or is relatively disconnected with the system. There are no CSFs in this cluster.
2. Cluster 2: Dependent variables. This cluster represents those factors which have strong dependences but weak driving power. There are three factors in this cluster, CSF2, CSF7, and CSF8.
3. Cluster 3: Linkage variables. These factors have strong driving as well as strong dependence power. There are three critical success factors which are CSF5, CSF6, and CSF9. These factors are unstable and any action on these will affect others.
4. Cluster 4: Independent variables/drivers. The independent factors have strong driving power but weak dependences. In this cluster, we have three CSFs which are CSF1, CSF3, and CSF4.

4.6 | Practical implication

It elaborate a list of CSF that are important and relevant for the development of blockchain for food supply chain for addressing traceability and trackability. This will facilitate the industry leaders to strategically focus on the main drivers that will ensure adoption and implementation of this disruptive technology.

5 | CONCLUSION

The primary purpose of this research is to develop a PCA-TISM-MICMAC integrated methodology for decisive identification of hierarchy among the CSF and provide sufficient information to managers and policymakers in successful integration of BC in FCS. The MICMAC analysis presents substantial information about the relative importance and interdependencies among these CSF. In this proposal, 19 CSF were identified after literature review and discussion with the industry experts, academicians, and people working in the BC and FSC industry. Using PCA, these 19 CSF were reduced to nine enablers; TISM methodology was employed to delineate mutual inter-dependence among them followed by MICMAC analysis to determine graphically from the four cluster the driving power and dependence for all the nine CSFS. The outcomes of this study can assist top management to understand the crucial areas where more emphasis is required in terms of appropriate decision making. By controlling these identified key inhibitors (with strong driving power and weak dependence) a paradigm shift can be accomplished in the field of BC for FCS. TISM-based model is not statistically validated. Structural equation modeling (SEM) can be utilized further to validate such theoretical models. However, TISM is capable enough to develop an initial model by utilizing different managerial techniques as nominal group techniques, brain storming, etc. In this way, TISM establishes as a supportive analytical tool for the present circumstances.

This paper presents a unique model for BC-based FSC management system that minimizes disruption and ensures robust performance and seamless flow of supply chain. Analyzing the inter-relationship among factors helped practitioners to determine driving and dependency of the factors. This will enable industries to concentrate on the right factors, identifying key risks and security at the implementation level and thus helping businesses and governments to reinforce the resilience of their networks.

6 | LIMITATIONS AND FUTURE DIRECTIONS

There is a possibility that the opinions received through the questionnaires from experts may represent limited exposure or knowledge about BC and FSC. The data may also vary with different geographical location, culture, political strata, and social and climate condition; and this parameter has not been considered in the present methodology. Finally, the research presented is still in the nascent stage, and academicians can further improve the suggested model with insight and analysis.[75]

In future, we are planning to apply the model in the real environment on large datasets, with various characteristics from the manufacturing industry.[76] The future work intends to use parameters like finance, policy, pollution, and energy to evaluate sustainable/smart BC. This would facilitate managers to evaluate from the portfolio of choice strategy, based on the requirement and accordingly take the decision. Artificial intelligence will be integrated for prediction and identification of sustainable BC, thus improving the accuracy and efficiency.[77]

BC can be integrated with IoT,[78–80] and the presented methodology can be extended to identify the enablers, drivers, and hierarchical model for strategizing and developing the business model.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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