Resources, Conservation & Recycling 152 (2020) 104505

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Blockchain critical success factors for sustainable supply chain

Sachin Yadav, Surya Prakash Singh*

Department of Management Studies, Indian Institute of Technology Delhi, 110016, New Delhi, India

ARTICLE INFO

Keywords:
Blockchain
Supply chain
PCA
Fuzzy
DEMATEL

ABSTRACT

Way back the development of Blockchain (BC) technology, Traditional supply chain (TSC) failed to meet the demand of customer of reasonable price with high quality. The current trend is the time to integrate and to make the existing system smarter, automated and sustainable. Researchers are working on the integration of information and communication technology with the supply chain (SC) and continuously endeavor to achieve an efficient SC. This paper is an attempt to study the use of BC technology and a try to develop efficient sustainable supply chain management (SSCM) rather than the inefficient design of supply chain management (SCM). Important variables related to BC are identified from the literature after going through discussion with academician and industry experts. These variables are further analyzed and modeled using Principal Component Analysis (PCA), Fuzzy-Decision making trial and evaluation laboratory (DEMATEL). PCA is applied to form the principal factor from these identified variables based on possible correlation. Although, the application of Fuzzy-DEMATEL is adopted to identify major causes that help to achieve sustainable supply chain (SSC) after integration of BC technology. The proposed integrated (incorporated) approach of PCA and Fuzzy-DEMATEL found six major causes namely Data safety and Decentralization, Accessibility, Laws and Policy, Documentation, Data management, and Quality. This study is revolving around the integrated approach of two streams namely BC-related Information technology and SC from Operations. This research represents the significant role of causes, which leads to the integration of BC with the SC resulting in achieving sustainability. BC technology is still in their nuance stage and this study will motivate researcher and industrial practitioners to achieve a more efficient and effective goal in SC practices to achieve sustainability.

1. Introduction

In recent time, the manufacturing organization and service sectors are conflicting due to the price war and high demand for quality. High quality and low price cannot be achieved without customer support (Cole et al., 2019) and the integration of new technology in the system. Several times it has been seen that customers are being faced various problems like late delivery without prior intimation, poor quality product, wrong product due to human negligence, broken or damaged product at the time of delivery, products expensive and painfully slow (Foster and Ganguly, 2007). Whenever investigation is carried out in these cases, no concrete outcome is being retrieved despite the cost investment and devotion of huge time. In the end, the customers remain unsatisfied and give negative feedback (Fawcett et al., 2007). Although, customers lost their interest and this led to the falling of overall performance and had put a question on the sustainability of SC.

Cryptographically secured chain of blocks concept was demonstrated by Haber and Stornetta (1992). After that BC use was attempted by Nakamoto (2008) and he used this technology as a cryptocurrency popularly known as Bitcoin. BC is known as Block chain as two separate words in Nakamoto (2008) original paper. This technology is based on a distributed ledger of information (Nakamoto, 2008). As its name suggests, it is made up of various blocks, each block having specific address information. Each block has a unique identity with unique information (Abeyratne and Monfared, 2016). It is impossible to change, erase, and update the information from BC (Madavi, 2019). In case to alter any information, a new block needs to be created for adding information. Due to this specific and unique quality, traceability (Steiner and Baker, 2015) and auditing at any juncture of the SC become efficient and effective. Rayes and Salam (2017) suggested that it make the system highly efficient with high transmission speed. The BC also reduces the cost and enhances the quality respectively as compared to the TSC. The recently manufacturing organization has started to implement BC for the improvement in SC performance (Korpela et al., 2017).

In the introducing stage of BC with SC, Tian (2016) suggested implementing the RFID for tracking the agricultural product in the SC using BC. Apart from agriculture, multinational companies like IBM, Comcast, Alphabet, etc. are currently investing in the research and

* Corresponding author.
E-mail address: sprsingh@dms.iitd.ac.in (S.P. Singh).

https://doi.org/10.1016/j.resconrec.2019.104505
Received 17 May 2019; Received in revised form 19 September 2019; Accepted 19 September 2019
Available online 09 October 2019

development department (Smetana et al., 2018) working on BC Technology. For example, Wallmart collaborated with IBM (Chopra, 2018) and implemented BC with IoT devices (RFID) in their stores. IBM used BC for its distinctive features and that is decentralization characteristics of BC technology. This decentralization characteristic does not allow storing data at one location; however, data is stored at several nodes located in the chain (Azaria et al., 2016). Decentralize feature of BC cannot be seen in the TSC, this characteristic is a big hurdle in front of the SC to make it sustainable. BC technology ensured that data change or hacking is not feasible in the SC after its integration and alleviate the customer's worries after quick tracking, consumes less time to investigate the problem. BC technology required the consumption of a few manpower although they should be highly skilled (Castillo, 2017) manpower. Iansiti and Lakhani (2017) have proposed the usage of BC innovation to actualize in the SC to make a more transparent, tamper-proof, profoundly exact, secure and distributed system, lastly, help to build up a SSC.

In the past few years, BC has got importance in industry and gradually being recognized as a game-changer for many industries like service, financial and manufacturing sectors. Because of its specific characteristics such as privacy, security, smart contract (Christidis and Devetsikiotis, 2016), scalability (Scherer, 2017), and ability to solve the double-spend problem, the need to make SCM more efficient becomes essential. BC implementation improves the transaction between two or more parties in terms of privacy, tracking, transparency and enforceability in smart contracts (Kosba et al., 2016). In the long run, the use of BC technology makes the SC system more energy-efficient (Zhang et al., 2018), cost-effective, and high performance oriented (King and Nadal, 2012). Application of BC technology can be used for improving the efficiency and effective use of resources and this latest technology will help to establish an SSC. BC is an emerging technology, and researchers and industry practitioners are trying to implement BC in the field of the SC. This technology is in its infancy phase (Queiroz and Wamba, 2019) and so far limited work has been carried out. Following are the main gaps in the area of BC especially in SSC.

1.1. Research gaps

- A limited study carried out on emerging BC technology.
- Few qualitative and quantitative approach is applied to BC-based SC.
- No approach is found in this field for the adoption of BC technology to make SC sustainable.

1.2. Research objectives

Considering above stated research gaps, the following research objectives are addressed in the paper

- To identify variables supporting the justification of BC-based SSC compared to the traditional method.
- To identify significant principal factor related to dimensions similarities with the help of PCA application.
- To develop a Cause-Effect relationship amongst principal factors to identify causes.

The rest of the paper is structured as: Section 2 provides a literature review of BC characteristics that are important for the SSC. Section 3 develops the proposed methodology and demonstrates the application of proposed integrated (combined) approach of PCA, and Fuzzy-DEMATEL. Section 4 provides results and discussion. Section 5 tells about the conclusion and implications. At last, Section 6 discusses the limitations and future directions.

2. Literature review

2.1. Past work on BC-based SC

In the global market, SCM plays a crucial role in reducing the operational cost (Gunasekaran et al., 2004). Every manufacturer wants to supply its articles at the lowest price in the hands of consumers. BC is seen as an advanced technology for cost reduction (Catalini and Gans, 2016) and quality enhancement, these nuances of BC would make the SC more robust. Korpela et al. (2017) elicit the integration of BC in SCM. Their center of attention was to improve the performance of the organization and cost-effective production by securing the data and transaction, distributed nature and transactions in peer-to-peer networks.

SC is day by day becoming more and more complex due to various causes like human error (Finch, 2004), disrupted services and climatic changes (Halldórsson and Kovács, 2010). Sullivan (1999), realized that 66 percent error found due to human error (Data lost) in his study (Broadcasters Network International). All these complexities result in a drop in performance and lead to the financial loss of the companies (Punter, 2013). At the international level, during the goods transported from one country to another, there is a need of time and a lot of paperwork with the involvement of huge manpower. All these procedures put a direct impact on manufacturer and retailer both in terms of high cost (Popper and Lohr, 2017), damage/misplace of goods, time consumption, cause of fraud (Popper and Lohr, 2017) and at last but not the least tax losses to the government.

In the year 1996, a scandal surfaced that got popular just because of child labor in NIKE's manufacturing factories in Asia (Connor, 2001). Another example where harsh work conditions caused Apple manufacturer factory known as "Foxconn suicide scandal" happened recently in 2010 (Moore, 2012). In the health industry, anti-cancer or other medicines are provided at a very high cost and this high cost and delay in delivery give chance to anti-national people to promote black marketing (Mackey and Nayyar, 2017). Customers ought to know about the capacity to recognize the historical backdrop of an item, how to utilize it, and where to return it and check all type of information available on BC.

BC helps to put transparency, security, traceability and also controls cost (Banerjee, 2018) from the manufacturer to the end-users via retailer/ supplier. Customers and end-users are unaware of the procedures, flow of goods at the production floor and hazard, misery involved in manufacturing, transportation, handling, etc. The flow of information helps customer to gain and regain the trust (Anjum et al., 2017). BC must guarantee the information to be truthful, valid and authenticated.

In the case of food production, sustainability standards and certifications provide support to organic food and better food life cycle (Elder et al., 2013). These types of accidents lead to the birth of new technology in manufacturing and supply system. Usage of BC has the advantages of security, irreversibility, distributed, transparency (Chiaroni et al., 2019), and accuracy (Iansiti and Lakhani, 2017). All these types of requirements will lead to motivate the integration of BC with SCM.

Experts from the various fields are doing work and are paying attention to achieve the SSCM because of challenges developed either by Government regulation or customer value demand (Luthra and Mangla, 2018). In 2018, INDIAN government has declared "Bitcoin" an application of BC illegal in their Union Budget but on another hand, the government is encouraging and opening various platforms for startup companies who are working on BC. Recently State Bank of India, India,

Table 1
Description of BC Characteristics.

Characteristics	Authors	Description
QUALITY ASSURANCE (**V1**)	Weber et al., 2016; Lucena et al., 2018; Benchoufi and Ravaud, 2017; Dai and Vasarhelyi, 2017	This characteristic makes the businesses easier in terms of investigation and guide to take a necessary step for the smooth flow of high-quality production of goods and services.
AUDITABLE (**V2**)	Shafagh et al., 2017; Azaria et al., 2016	BC technology serves as a repository of the transaction history. This makes accessibility, management, and auditability more efficient.
SCALABILITY IN SCM (**V3**)	Scherer, 2017; Madavi, 2019	This makes integration of BC without losing data consistency. When information is recorded in a block of BC, it is non-variable, non-voletile and the appropriated stockpiling highlight makes digital assaults troublesome.
TRANSPARENCY (**V4**)	Nugent et al., 2016; Iansiti and Lakhani, 2017	It makes transactions between peer to peer are verified at the minor end and updated data cannot be changed or hacked. The BC property of changing anything in the ledger which then stays on it makes it a transparent system.
ENERGY **(V5)**	Zhang et al., 2018; King and Nadal, 2012	Nowadays energy is quite expensive. BC saved energy by tracking takes less time, easily auditable, save paper, transport cost in term of feedback, etc.
INTEGRITY (**V6**)	Tian, 2016; Drugs, 2004; Mangla et al., 2019	It provides management and physical goods flow in the SC using the integration of serial numbers, bar codes, sensors, digital tags like RFID, etc with BC became smoother from manufacturer to end-user.
SOLVING THE DOUBLE SPEND PROBLEM (**V7**)	Bartling and Fecher, 2016; Lundqvist et al., 2017	Double spend means the same Data/ transaction cannot be sent to two or more persons at the same time. Peer to peer transaction is authenticated after the verification carried by a minor.
HIGH-QUALITY DATA (**V8**)	Weber et al., 2016; Sullivan, 1999; Azaria et al., 2016	BC data is completing, consistent, timely and accurate. It keeps the data which is free from human error, means 100% accurate and authenticated data available on BC network.
SMART SYSTEM (**V9**)	Bitfury Group, 2015; Iansiti and Lakhani, 2017	Tedious authoritative exchanges can bottleneck the development of a business. With shrewd contracts, understandings can be naturally approved, marked and upheld through a BC.
GOVERNMENT POLICY (**V10**)	Ølnes et al., 2017; Luthra and Mangla, 2018	It is a big challenge in front of SC organizations. It helps to find out a scam in any organization by quickly during an audit.
IMMUTABILITY AND ENCRYPTION (**V11**)	Weber et al., 2016; Saberi et al., 2018	After confirmation of any transaction or flow of data from one place to another, it is impossible to change as well as any change on the BC can be stored without the solidarity of the network.
DURABILITY, RELIABILITY, AND LONGEVITY (**V12**)	Niranjanamurthy et al., 2018; Saberi et al., 2018	It eliminates the risk of system failure, loss of data, malicious attack and involvement of central authority. All the transactions records and data flow information are authenticated and protected.
SPEED (**V13**)	Zhu and Zhou, 2016	This characteristic is required for those articles whose life cycle are very low like some chemicals, vegetables, and fruits, in this situation BC-based SCM save product's life and help to maintain quality.
PERMANENCE (**V14**)	Weber et al., 2016; Saberi et al., 2018	This makes the data fully permanent and free from erasing or deletion.
FEEDBACK (**V15**)	Peters et al., 2015; Foroglou and Tsilidou, 2015	With full traceability of the article throughout the lifecycle of it and backflow information during the reshipment, installation, maintenance and decommissioning.
AUTOMATION (**V16**)	Bartling and Fecher, 2016	Automation is defined as non-availability of intermediaries, peer to peer transaction flow, updated by minors and data saved automatically and the distributed ledger characteristic made the network real-time.
ACCOUNTING (**V17**)	Dai and Vasarhelyi, 2017	Recorded transactions through BC abolish the human error and provide the data security from the hacking and possible interferences.
EFFICIENCY (**V18**)	Ahram et al., 2017; Smetana et al., 2018	The high rate of information flow speed, no intermediary is required, smart contracts, easily traceable and finally it streamlines the processes considerably, which in turn save time and money.
INFORMATION FLOW AND CONTROL (**V19**)	Korpela et al., 2017; Saberi et al., 2018	This provides real-time customer response for BC technology. Steady feedback conveyed to retailers and manufacturers for more accurate forecasts.
IMPROVEMENT IN INVENTORY (**V20**)	Korpela et al., 2017; Lucena et al., 2018	This BC characteristic makes the management of inventory is much easier since everyone holds a copy of the information.
QUALITY FAIRNESS (**V21**)	Weber et al., 2016; Iansiti and Lakhani, 2017	This makes the data shared between various nodes free from bias, human error, transparent, no hidden information about goods and suppliers, etc.
ECOSYSTEM SIMPLIFICATION (**V22**)	Bartling and Fecher, 2016	This characteristics make the network simpler in the ecosystem and reduce the complexity of multiple ledgers.
NEAR IMPOSSIBLE LOSS OF DATA (**V23**)	Weber et al., 2016; Madavi, 2019	It is practically impossible of being hacked and loses stored data on a BC, as a full copy of data records are available at each node of the ledger and minor on the network.
SECURITY (**V24**)	Iansiti and Lakhani, 2017; Kshetri, 2018	Once Block has been created, it is impossible to delete or change in it. This feature makes the security of SC more refine after the adoption of BC in the existing traditional methods.
REDUCTION IN ADMINISTRATIVE COST (**V25**)	Bashir, 2017; Catalini and Gans, 2016	Reduction in paper and another consumable item, time-saving, quick discussion, better management and administration, shared database means less administrative work.
IDENTIFICATION OF ISSUES (**V26**)	Michal et al., 2018	With the integration of BC in the SC, whenever there is something wrong with an inventory item, it would show up in the chain of custody. It reduces or nearly eliminates the human error from the system.
REMOVAL OF INTERMEDIARIES (**V27**)	Weber et al., 2016; Gatteschi et al., 2018	BC provides the platform for a direct transaction without the interference of intermediaries or a third party.
DATA ACCESS CONTROL IN SCM (**V28**)	Swan, 2015; Korpela et al., 2017	This characteristic makes the BC a distributed ledger, stored all needed data.
STREAMLINED INVOICING (**V29**)	Koch, 2016	Any purchase order recorded and rendered fundamentally unalterable as a block in the chain, and finally make the SCM streamlined.

(*continued on next page*)

Table 1 (*continued*)

Characteristics	Authors	Description
LAWS (**V30**)	Werbach, 2018; De Filippi, 2018; De Filippi and Hassan, 2018	It provides smart contracts to allow having the performance of credible transactions without third parties. It will deprive you of the need to perform any digital actions yourself when certain conditions are met. Data cannot be deleted or modified, hence no chance of fraud.
HIGHLY AVAILABILITY (**V31**)	Ølnes et al., 2017; Liang et al., 2017	Thousands of nodes are spread in the distributed ledger network. Data remains available all the time. The transaction can be done at any time due to the high availability of data on the network, even after crashing of any node or quit of the node.
DISINTER-MEDIATION (**V32**)	Bogart and Rice, 2015; Bartling and Fecher, 2016	Public BC technology based on distributed ledger never deploys central administrator for data sharing. Transactions records never get stored any hard disk or database storing devices.
SIMPLIFICATION OF CURRENT PARADIGMS (**V33**)	Bashir, 2017	It makes the BC fill in as a solitary shared record among individual interested investers, bringing about disentangling this model by decreasing the multifaceted nature of dealing with the different frameworks kept up by every element.
DECENTRALIZATION (**V34**)	Zyskind and Nathan, 2015; Anjum et al., 2017; Iansiti and Lakhani, 2017	BC is a system of teaming up gatherings with a database that is decentralized. This implies most gatherings that team up on a BC have their own duplicate of the considerable number of exchanges that are put away on the BC
CUSTOMER CENTRICITY (**V35**)	Raju et al., 2017; Tian, 2016	A transparent solution made communication more stream-line and automated with customers, enabling also a higher trust level. Upgraded clearness into the SC and knowing the source of an item is an extraordinary trust-manufacturer – coming to past provider data, by offering continuous, 'live' and reliably 'associated' refreshes.
SHARING DEMAND IN SCM (**V36**)	Ølnes et al., 2017; Tian, 2016	Sharing demand in SCM is the flow of shared information about the maintenance, supply, and manufacturing process, set up and assembly from manufacturer to supplier and SME vendors.
COST (**V37**)	Bashir, 2017; Catalini and Gans, 2016; King and Nadal, 2012; Wüst and Gervais, 2018	Along with much lower costs due to the removal of intermediaries, due to low transaction fees, overhead costs for exchanging assets cut down in the paperwork by 15%.
TRACEABILITY AND VISIBILITY (**V38**)	Rob Price, 2015; Everledger, 2016	Traceability and Visibility mean following merchandise in a SC can be beneficial when trying to follow where parts are right now living. In a basic manner, it tells about the geological area/ location of the goods.
TRUST-WORTHY SYSTEM (**V39**)	Anjum et al., 2017	Trust-worthy system is imparted by BC technology by knowing the origin of a product by offering real-time, live and consistently connected updates.

has organized a workshop related to bank security via BC and distributed the prize to winners.

Juniper Research Conducted a study amongst 369 MD, CEOs, managers and all this study said that more than 76 percent gave a vote to implement BC and less than 24 percent said BC is quite beneficial for the industry. Implementation of BC in the manufacturing and services industry will show the possibility of employment (Castillo, 2017) for unemployed youth. The European Community Directive Waste Electrical and Electronic Equipment (WEEE) Directive is adopted globally. It has circular economy, closed-loop SCs, and reverse logistics implications. It requires item stewardship and returns arrangements with terms and conditions for hardware that can be tended to with BC innovation reception (Saberi et al., 2018).

The following section provides various BC characteristics used in SSC.

2.2. BC characteristic for SSC

To integrate BC in the SC, the following characteristics important for the integration are identified. These are identified from the published literature and based on one to one discussion with industry experts.

BC characteristics are identified from the literature review section. They are considered and further factorized using PCA. Principal Factors obtained from PCA are analyzed in the next step using Fuzzy-DEMATEL approach to count the cause-effect for the SSC (Table 1).

3. Proposed methodology

This section proposes a methodology considering PCA, Fuzzy-DEMATEL used in the paper to address research gaps and objectives. The proposed research flow chart is depicted below in Fig. 1.

3.1. Factorization of variables using PCA

PCA is a mathematical tool used mostly for the gathering of factors from the group of various variables. PCA methodology is based on the statistical procedure where data is collected from respondents that are expert in their fields using, Likert, scale from strongly agree (1) to strongly disagree (2) using scale 1–9. Fig. 2 shows the PCA flow chart for thirty-nine variables.

Here, 39 different variables are scaled and then factorized into 12 Principal factors, shown in Table 2. PCA is used for reducing the dimensionality of data set into two or three axes with low variance and high correlations (Jackson and Hearne, 1973). Flowchart representing PCA is shown in Fig. 2.

PCA is used here to generate the principal component or axis from the computation of linear combinations of the real variables. Data ratio is used for getting the accurate and reliable factorized by using the variables ratio more than 1:5 (Jackson and Hearne, 1973) Excel and XLSTAT software is used to analyze the set of data collected from experts shown in Appendix A. PCA used varimax rotation to calculate how appropriate the data collected is from expert choice. In this work, the KMO value is found to be 0.626. Steps for PCA are taken from Kumar et al. (2018) and KMO methodology adopted from Mishra et al. (2019).

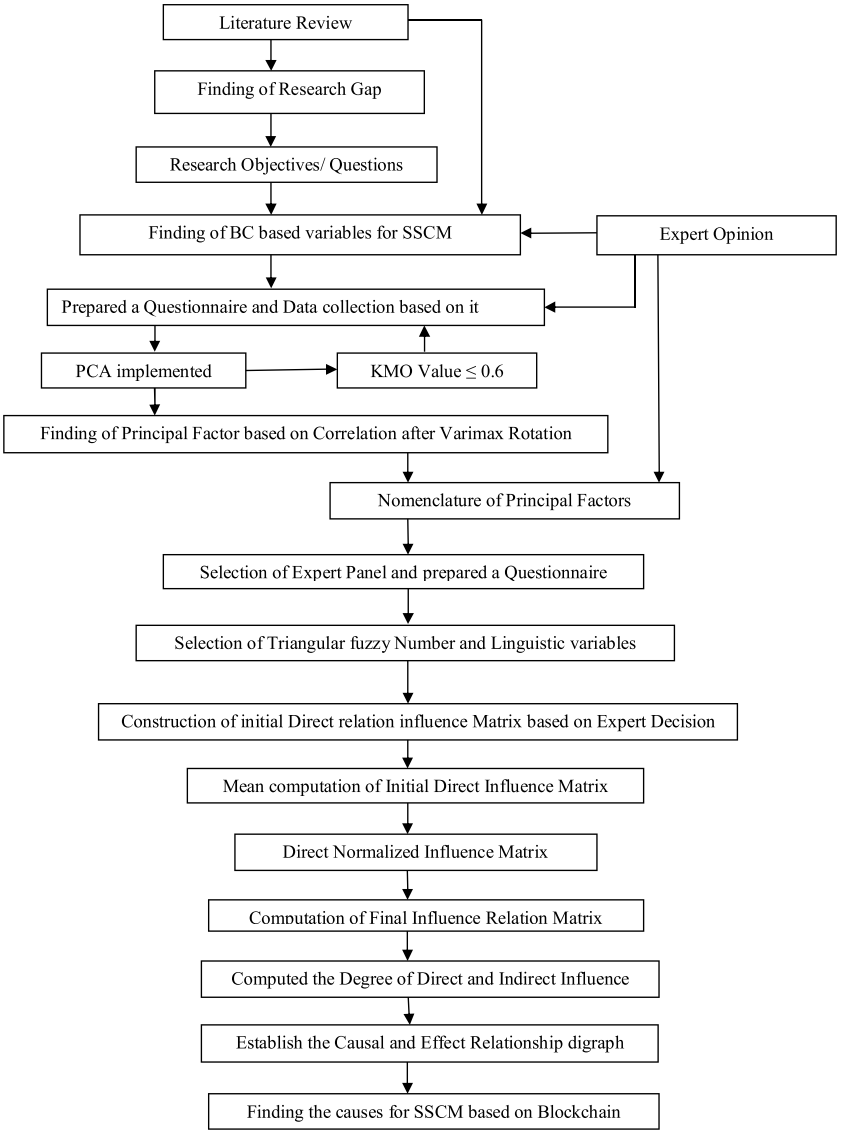

Fig. 1. Research flow chart.

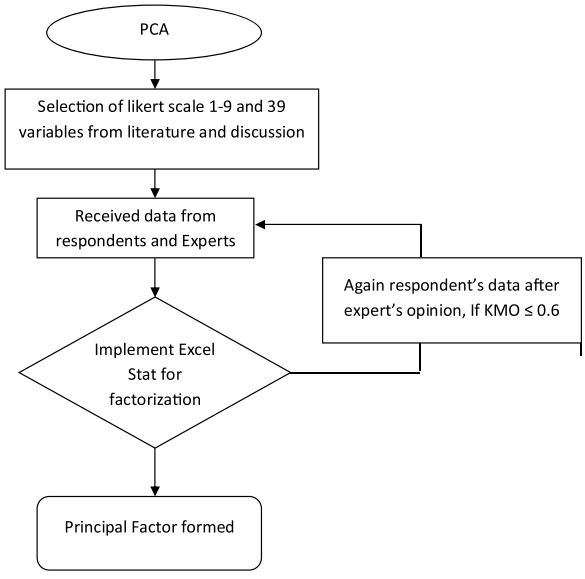

Fig. 2. PCA flow chart for factorizationthirty-nine variables.

The variables having the same or approx value of correlation are club together to form a Principal factor. Flow diagram of PCA selection and its methodology is described in Fig. 2 and factorization of variables is shown in Table 3 and highlighted cells in the table show correlation.

After the implementation of PCA, thirty-nine variables are factorized on the basis of close correlation values. Common nomenclature was given to Principal factor after discussion with a panel consisting of a group of experts. Definitions of the Principal factors are described as below in Table 4:

3.2. Step 3.2: Fuzzy-DEMATEL

Decision-making trial and evaluation laboratory (DEMATEL) is an MCDM tool widely applied in both qualitative and quantitative analysis developed by Battelle Memorial Institute of Geneva during 1972-76. It is an effective method to resolve the complex relationship by constructing a casual effect relationship among the factors (Luthra et al., 2017). Recent application of DEMATEL (Kumar and Dixit, 2018; Chauhan et al., 2019) and its Fuzzy application (Tzeng et al., 2007; Opricovic and Tzeng, 2003; Islam et al., 2018) and work based on Fuzzy application can be referred from Tzeng et al. (2007) and Gharakhani (2012).

Table 2
Eigenvalues of identified factors.

Principal Factor	Eigenvalue	Variability (%)	Cumulative (%)
V1	7.569	19.409	19.409
V2	3.876	9.937	29.346
V3	3.244	8.317	37.663
V4	2.798	7.173	44.836
V5	2.525	6.474	51.310
V6	2.202	5.646	56.956
V7	2.067	5.300	62.256
V8	1.946	4.990	67.246
V9	1.735	4.449	71.695
V10	1.568	4.021	75.716
V11	1.538	3.943	79.659
V12	1.294	3.318	82.976
V13	1.242	3.185	86.161
V14	1.136	2.912	89.074
V15	1.030	2.640	91.714
V16	0.822	2.108	93.822
V17	0.635	1.629	95.450
V18	0.562	1.442	96.892
V19	0.550	1.409	98.301
V20	0.448	1.147	99.449
V21	0.068	0.174	99.623
V22	0.040	0.102	99.725
V23	0.038	0.097	99.821
V24	0.027	0.070	99.891
V25	0.018	0.047	99.938
V26	0.017	0.043	99.981
V27	0.007	0.019	100.000

Following are the steps of Fuzzy-DEMATEL applied here.

Step i: Selection of the expert panel and construct of questionnaire

Here, five different panels are formed each comprised of three experts. A questionnaire was designed keeping in view the use of BC in the SC. Linguistic variables No influence **(N),** Very low influence **(VL),** low influence **(L),** High influence **(H),** Very high influence **(VH)** are used in the questionnaire to collect responses as shown in Table 5. The influence matrix given by all panel and the pairwise comparison fuzzy matrix computed from the influence matrix is shown in appendix B.

Step ii: Construction of crisp matrix

Crisp matrix was constructed by using the Eqs. (1)–(6). Crisp values against pairwise comparison fuzzy matrix are shown in appendix B.

Compute the crisp value (CV) by using the following formulas:

Step i: Compute the L, R, Δ from Eq. (1)

$$L = \min(l_K);\ R = \max(U_K);\ K = 1,2,3.....nand\Delta = R - L \tag{1}$$

Step ii:

$$X_{lk} = \frac{l_k - L}{\Delta};\ X_{mk} = \frac{m_k - L}{\Delta};\ X_{uk} = \frac{U_k - L}{\Delta} \tag{2}$$

Step iii: Compute left score normalized and right score normalized values from Eqs. (3) and (4)

$$X_k^{ls} = \frac{X_{mk}}{1 + X_{mk} - X_{lk}} \tag{3}$$

$$X_k^{rs} = \frac{X_{uk}}{1 + X_{uk} - X_{mk}} \tag{4}$$

Step iv: Compute the total normalized CV from Eq. (5)

$$X_k^{crisp} = \frac{(X_k^{ls} \times (1 - X_K^{ls}) + X_k^{rs} \times X_k^{rs})}{1 + X_k^{ls} - X_k^{rs}} \tag{5}$$

Step v: Compute final CV from Eq. (6)

$$Z_{ij}^n = L + X_k^{crisp} \times \Delta \tag{6}$$

Step vi: Compute the average CV from Eq. (7)

$$Z_{ij}^n = \frac{Z_{ij}^1 + z_{ij}^2 + z_{ij}^3 + ... + z_{ij}^n}{numberofExperts} \tag{7}$$

A similar procedure has been adopted by other four expert panels for computing the individual crisp matrix. Final crisp matrix computed after the average opinion of the expert's panel is shown in Table 6. Using Eq. (7) the aggregated opinion of the expert panel is computed which is shown in Table 6, computing the average of expert's panel.

Step iii: Mean computation of initial direct influence matrix

In step 3, the mean of all initial direct influence matrices is computed using Eq. (8) (Lamba and Singh, 2018; Rajput and Singh, 2018).

$$C_{ij} = \frac{\sum_1^n E_{ij}}{number\ of\ Experts\ matrices} \tag{8}$$

Step iv: Computation of direct normalized influence matrix (DNIM)

DNIM is obtained using Eqs. (9) and (10). DNIM is shown in table 12.

$$\lambda = min_{(i,j)}\left[\frac{1}{max_i \sum_{j=1}^n C_{ij}} or \frac{1}{max_j \sum_{i=1}^n C_{ij}}\right] \tag{9}$$

$$DNIM = \frac{IDIM}{\lambda} \tag{10}$$

Step v: Computation of final influence relation matrix

After calculating the direct normalized influence matrix in step iv, total influence relation matrix obtained using Eq. (11) (Lin et al., 2018; Khatwani et al., 2015). The total influence relation matrix is shown in table 13.

$$R = D \times (I - D)^{-1};\ \text{"I" } represents\ identity\ matrix \tag{11}$$

4. Results and discussion

Thirty-nine BC variables are identified from the literature and expert opinion which is further factorized into twelve factors (Principal Factors) using PCA. These twelve factors are System robustness (PF 1), Overall cost (PF 2), Overall performance (PF 3), Data safety and Decentralization (PF 4), Accessibility (PF 5), Laws and Policy (PF 6), Smart system (PF 7), Customer satisfaction (PF 8), Reliable system (PF 9), Documentation (PF 10), Data management (PF 11), and Quality (PF 12). Driving enablers (Causes) are identified among these twelve factors using Fuzzy-DEMATEL. The casual effect diagram is built up between $R_i + C_i$ and $R_i - C_i$ is an outcome of Fuzzy-DEMATEL, which is shown in Fig. 3. For the computation of $R_i + C_i$ and $R_i - C_i$ values against each principal factor's detailed explanation is available in section vi (Tables 7–9).

Step vi: Establishing causal and effect relationship

In the final step, the sum of each row and sum of each column from table 13 is calculated respectively and denoted by "C_i" and "R_i". Here, R_i represents the direct effect given and C_i represents the indirect effect received by one factor to another factor. $R_i + C_i$ and $R_i - C_i$ are calculated that represents the relative contribution of the factor in the system and from the system (Bhatia and Srivastava, 2018, Mathivathanan et al., 2018).

From the Fig. 3, it can be seen that factors viz. data safety and decentralization (PF 4), accessibility (PF 5), law and policy (PF 6), documentation (PF 10), data management (PF 11), and quality (PF 12) are causing effect while others are being affected. These causing factors are

Table 3
Factorization of Variables into Principal Factors after Varimax rotation.

Variables	PF1	PF2	PF3	PF4	PF5	PF6	PF7	PF8	PF9	PF10	PF11	PF12
Quality assurance (V1)	0.026	0.115	-0.013	0.038	0.061	-0.011	-0.040	0.032	-0.035	-0.003	-0.112	0.965
Auditable (V2)	-0.034	0.072	0.076	-0.013	0.029	0.022	0.132	0.020	0.032	0.933	0.079	-0.014
Scalability (V3)	0.302	-0.104	-0.089	0.049	0.293	-0.173	-0.038	-0.165	0.719	-0.043	0.054	0.045
Transparency (V4)	0.461	-0.032	0.448	0.126	0.220	-0.179	0.411	0.110	-0.062	0.180	0.030	0.126
Energy (V5)	0.025	0.963	0.084	-0.018	0.065	-0.015	0.087	-0.005	0.026	0.041	-0.063	0.082
Integrity (V6)	0.075	0.067	0.079	-0.018	0.972	-0.016	0.036	0.036	0.094	0.026	0.053	0.042
Solving the double speed problem (V7)	0.928	0.024	0.073	-0.097	0.073	0.054	0.048	0.109	0.151	-0.034	0.066	0.013
High quality data (V8)	0.071	-0.138	0.026	-0.076	0.086	0.065	0.023	0.067	0.110	0.121	0.868	-0.179
Smart system(V9)	0.078	0.164	-0.070	-0.030	0.052	0.044	0.874	-0.089	0.069	0.155	0.012	-0.061
Government policy (V10)	0.053	-0.021	0.007	0.020	-0.025	0.962	0.016	-0.039	-0.088	0.019	0.052	-0.009
Immutability (V11)	-0.184	-0.102	-0.009	0.878	-0.065	0.112	-0.029	0.104	0.090	-0.057	-0.134	-0.004
Durability, reliability, longevity (V12)	0.163	0.198	0.247	-0.017	0.073	-0.051	0.160	0.227	0.728	0.122	0.151	-0.129
Speed (V13)	-0.083	0.125	0.522	0.034	-0.019	-0.041	0.430	0.362	0.052	-0.044	0.311	-0.060
Permanence (V14)	0.079	0.257	0.132	0.625	0.056	-0.229	0.015	-0.222	-0.233	0.161	0.291	0.224
Feedback (V15)	0.209	-0.027	0.004	0.025	0.060	-0.056	-0.071	0.888	0.018	0.032	0.040	0.036
Automation (V16)	0.145	0.153	0.850	0.005	0.170	0.036	-0.121	-0.041	0.053	0.128	-0.013	-0.013
Accounting (V17)	0.176	-0.013	0.149	0.078	0.349	-0.094	0.258	0.212	0.006	0.511	-0.049	0.136
Efficiency (V18)	0.090	-0.016	0.475	-0.020	-0.021	0.081	0.221	0.102	0.337	0.032	0.240	-0.013
Information flow and control (V19)	0.022	0.006	0.176	0.219	0.203	0.154	0.144	-0.041	0.157	-0.105	0.485	0.280
Improvement in Inventory (V20)	0.341	-0.076	0.186	0.118	0.115	-0.069	0.365	0.135	0.130	0.101	0.202	0.052
Quality fairness (V21)	0.026	0.115	-0.013	0.038	0.061	-0.011	-0.040	0.032	-0.035	-0.003	-0.112	0.965
Ecosystem simplification (V22)	-0.052	0.059	0.092	-0.001	0.010	0.031	0.098	0.019	0.038	0.940	0.111	-0.014
Near impossible loss of data (V23)	0.302	-0.104	-0.089	0.049	0.293	-0.173	-0.038	-0.165	0.719	-0.043	0.054	0.045
Security (V24)	0.461	-0.032	0.448	0.126	0.220	-0.179	0.411	0.110	-0.062	0.180	0.030	0.126
Administration Cost (V25)	0.025	0.963	0.084	-0.018	0.065	-0.015	0.087	-0.005	0.026	0.041	-0.063	0.082
Identification of Issues (V26)	0.075	0.067	0.079	-0.018	0.972	-0.016	0.036	0.036	0.094	0.026	0.053	0.042
Removal of intermediaries (V27)	0.923	0.043	0.067	-0.098	0.075	0.055	0.048	0.138	0.150	-0.030	0.029	0.008
Data access control in SCM (V28)	0.071	-0.138	0.026	-0.076	0.086	0.065	0.023	0.067	0.110	0.121	0.868	-0.179
Streamlined invoicing (V29)	0.078	0.164	-0.070	-0.030	0.052	0.044	0.874	-0.089	0.069	0.155	0.012	-0.061
Laws (V30)	0.053	-0.021	0.007	0.020	-0.025	0.962	0.016	-0.039	-0.088	0.019	0.052	-0.009
Highly availability (V31)	-0.180	-0.138	-0.044	0.848	-0.043	0.084	0.001	0.125	0.093	-0.050	-0.167	-0.026
Disintermediation (V32)	0.163	0.198	0.247	-0.017	0.073	-0.051	0.160	0.227	0.728	0.122	0.151	-0.129
Simplification of current paradigms (V33)	-0.083	0.125	0.522	0.034	-0.019	-0.041	0.430	0.362	0.052	-0.044	0.311	-0.060
Decentralization (V34)	0.089	0.262	0.134	0.616	0.052	-0.215	0.004	-0.235	-0.223	0.146	0.316	0.217
Customer centricity (V35)	0.230	-0.012	0.012	0.041	0.076	-0.037	-0.050	0.887	0.039	0.054	0.058	0.056
Sharing demand in SCM (V36)	0.152	0.190	0.822	0.001	0.150	0.033	-0.147	-0.069	0.096	0.125	-0.014	-0.017
Cost (V37)	0.025	0.963	0.084	-0.018	0.065	-0.015	0.087	-0.005	0.026	0.041	-0.063	0.082
Traceability (V38)	0.075	0.067	0.079	-0.018	0.972	-0.016	0.036	0.036	0.094	0.026	0.053	0.042
Trust worth system (V39)	0.914	0.043	0.078	-0.094	0.079	0.056	0.032	0.131	0.152	-0.027	0.028	0.017

considered as driving factors for the SSC after integration of BC in SCM. Eq. (12) shows the set of driving factors obtained from Fuzzy-DEMATEL.

Set_of_driving_criteria_Fuzzy-DEMATEL = {Data safety and Decentralization (PF 4), Accessibility (PF 5), Laws and Policy (PF 6), Documentation (PF 10), Data management (PF 11), and Quality (PF 12)} (12)

5. Conclusion and implications

In the current era, experts from industry, academics, and practitioner are keeping their focus on how to improve the performance of SCM. Authors have tried to sustain the SC with the integration of BC technology. Role of IoT and other devices related to Industry 4.0 is not only to improve performance and operational excellence in the traditional SC but also to transform it into SSC (Mangla et al., 2019). In this paper, authors have found the causes for the SSC after the integration of a new technology "BC" with the SC. This paper has investigated the driving criteria of BC for implementing it with the SC and make it more robust and sustainable. The current proposed research work identifies thirty-nine variables after studying numerous literature reviews and after having a discussion with SC experts, practitioners, and academicians having knowledge of BC. PCA is applied in the paper for factorization having similar correlation values and reduced the dimensions. Thirty-nine characteristics have been reduced to twelve, based on similar correlation value after varimax rotation and in PCA. In PCA, KMO value is also computed and found more than 50 percents; it justified the data authenticity in PCA. These Principal factors are used in Fuzzy-DEMATEL. Fuzzy-DEMATEL is a very helpful tool and widely implemented in various kind of industries, used to troubleshot problems in

Table 4
Description of Principal Factors.

Principal factors	Description
System robustness (**PF1**)	System robustness factorized into five variables like transparency, security, removal of intermediaries, and trusts worthy system and solves the double speed problem. Transparency in information flow, stability to data means once stored cannot be changed or deleted, peer to peer transaction without involving of a third party, all these types of characteristics made the SC and system more robust and sustainable after integration of BC.
Overall cost (**PF2**)	The overall cost is formed by clubbing three variables namely cost, energy, administrative cost based on their correlative value near to 0.963. Overall cost includes all financial investment in the SC like documentation fee, stationery expenditure, manpower, electricity, facility, documentation carrying a cost, time, etc.
Overall performance (**PF3**)	Overall performance shows the performance of the organization in term of efficiency, effectiveness, and speed of doing the job in the right direction with right standardization, low response, and reduction in complexity of the job. It is formed by clubbing five variables namely efficiency, speed, automation, simplification of current paradigms and sharing demand in SC based on their correlative values.
Data safety and Decentralization (**PF4**)	Experts give name Data safety and decentralization name given by experts to a group of four variables which are comprised after implementation of PCA tool. Information and records of standardization, process, and supply of the goods are very important for all peoples who are involved in the system directly or indirectly. Hacking of data, change of data, controlling authority, loss of data due to any reason, data stability and reliability is possible only on BC integrated SC.
Accessibility (**PF5**)	Traceability/ Visibility, Identification of issues and integrity are three variables factorized together to form a common factor called accessibility based on their correlation values equal to 0.972. Accessibility means tracing of causes, goods location, accident, fraud happening in between the process of the SC from manufacturer to end-user with the help of IoT/ Industry4.0.
Laws and Policy (**PF6**)	Laws and policy documentation work make it very complicated, time-consuming. For any contract "documents" play the key role but this public ledger technology gives us transparency and high speed up work and checks corruption in governments and also help to find out a scam in any organization by quickly during an audit. For any legal action, data records are very important. In this technology data cannot be deleted or modified, hence no chance of fraud. Law and Government policy are two variables factorized together to form a common factor called accessibility based on their correlation values equal to0.962.
Smart system (**PF7**)	The smart system comprised of smart contract, streamlined invoicing and improvement in inventory. It eliminates any type of fraud in the documentation, pays taxes on time without losing time in documentation, wrong delivery of goods from the shipyard area.
Customer satisfaction (**PF8**)	Customer satisfaction is the integration of feedback, Customer Centricity on the ground of expert's opinion. Customer satisfaction means positive feedback and positive response from the customer. It can be achieved after delivery of the right product with the right information at a time, right place in the right hand with the commitment of periodical service after the sale.
Reliable system (**PF9**)	Reliable System factorized into four variables like Scalability, near impossible loss of data, Disintermediation and Durability, Reliability, Longevity. BC keeps the records of raw, semi-finished, finished material at every location. IT not only reduces time but also reduce the money by keeping the right information about the goods.
Documentation (**PF10**)	Documentation is comprised of Auditable, Accounting, and Ecosystem Simplification. BC is keen in integration for the following reason like smooth audit purpose and simplification of finance, smooth flow of currency.
Data management (**PF11**)	Data management means management of data in term of controlling the end-users access, controlling the two transactions from a single account at a time, eliminate human mistake in the documentation and in other work, real-time information flow. Data management factorized into three variables high-quality data, information flow and controls, and data access control in SC.
Quality (**PF12**)	Quality is factorized into quality assurance and quality fairness. Quality means goods and SC free from any kind of irregularity in process, transportation, leads down in specification of raw material. Elimination of human error and availability of full information.

Table 5
Linguistics values.

Linguistics terminology	Triangular fuzzy numbers	Influence scale
No influence **(N)**	(0,0,0.25)	0
Very low influence **(VL)**	(0,0.25,0.5)	1
low influence **(L)**	(0.25,0.50,0.75)	2
High influence **(H)**	(0.50,0.75,1)	3
Very high influence **(VH)**	(0.75,1,1)	4

group decision-making in a fuzzy environment. Fuzzy application is used to count the uncertainty, imprecise and inaccurate information collected from experts. Because of these focal points, DEMATEL is utilized to uncover superior learning of the impacts of the examination of causes and effect criteria and to expand the model applicability. These techniques are used here, to identify driving enablers among twelve principal factors obtained from PCA. Moreover, this paper shows six factors viz. Data safety and Decentralization (PF 4), Accessibility (PF 5), Laws and Policy (PF 6), Documentation (PF 10), Data management (PF

Table 6
Aggregated crisp matrix.

	PF 1	PF 2	PF 3	PF 4	PF 5	PF 6	PF 7	PF 8	PF 9	PF 10	PF 11	PF 12
PF 1	0	0.509778	0.523778	0.422667	0.481778	0.178444	0.287333	0.696444	0.25	0.200222	0.502	0.422667
PF 2	0.064889	0	0.351111	0.214222	0.430444	0.064889	0.488	0.178444	0.178444	0.208	0.106889	0.307556
PF 3	0.488	0.243778	0	0.092889	0.164444	0.057111	0.243778	0.502	0.236	0.057111	0.307556	0.386889
PF 4	0.775778	0.374444	0.509778	0	0.416444	0.424222	0.402444	0.374444	0.064889	0.237556	0.158222	0.237556
PF 5	0.775778	0.208	0.696444	0.452222	0	0.775778	0.509778	0.638889	0.603111	0.502	0.718222	0.603111
PF 6	0.603111	0.158222	0.372889	0.351111	0.251556	0	0.797556	0.271778	0.214222	0.696444	0.386889	0.351111
PF 7	0.589111	0.293556	0.502	0.315333	0.257778	0.257778	0	0.416444	0.201778	0.374444	0.251556	0.200222
PF 8	0.315333	0.178444	0.581333	0.186222	0.172222	0.214222	0.559556	0	0.015111	0.106889	0.050889	0.559556
PF 9	0.164444	0.444444	0.386889	0.078889	0.029111	0.043111	0.136444	0.029111	0	0.100667	0.100667	0.122444
PF10	0.279556	0.718222	0.372889	0.229778	0.271778	0.337111	0.386889	0.279556	0.122444	0	0.215778	0.064889
PF11	0.561111	0.337111	0.502	0.309111	0.388444	0.150444	0.287333	0.374444	0.158222	0.374444	0	0.295111
PF12	0.589111	0.603111	0.696444	0.208	0.279556	0.071111	0.337111	0.934444	0.329333	0.142667	0.523778	0

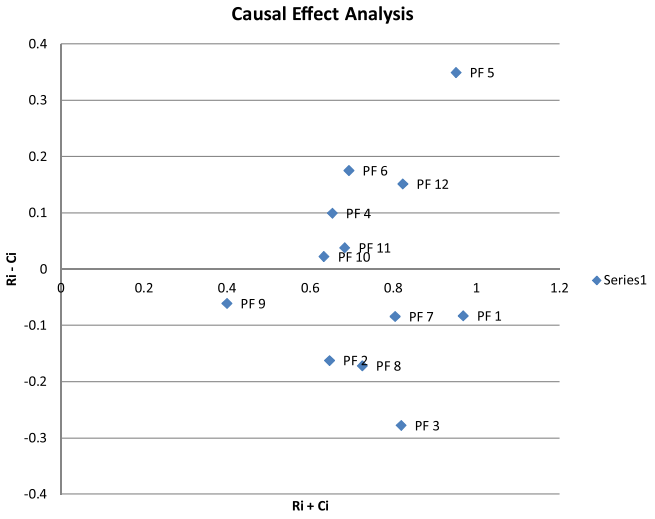

Fig. 3. Causal Effect Analysis.

11), and Quality (PF 12) as Outcome of Fuzzy-DEMATEL in the form of cause.

These six causes will help to develop a strategy and will give a platform for new developing businesses based on global SC and how to face challenges. Industries are implementing BC and doing better performance due to it although, facing problem while implementing or running on it. Thus, this research works presents a novel approach to BC technology for the sustainability of the SC. This research is in its nuance stage and will motivate researchers, academician, and practitioners to implement BC and troubleshot of live problems in the SSC and will help to develop new theory, find the root cause and help for doing trouble-shoot because of BC. This study imparts the cause for implement BC towards stakeholders and investors, in place of the existing method of supply.

Table 9
Computed the degree of direct and indirect influence.

Principal Factor	C_i	R_i	$R_i + C_i$	$R_i - C_i$
PF 1	0.525197923	0.442580471	0.967778393	−0.08261745
PF 2	0.403888131	0.241985293	0.645873424	−0.16190284
PF 3	0.547671481	0.270418993	0.818090473	−0.27725249
PF 4	0.276627371	0.37617964	0.652807011	0.099552269
PF 5	0.300193533	0.650064231	0.950257764	0.349870699
PF 6	0.258701396	0.434333046	0.693034442	0.17563165
PF 7	0.443936735	0.359996176	0.803932911	−0.08394056
PF 8	0.448368781	0.276850089	0.72521887	−0.17151869
PF 9	0.230047689	0.169335364	0.399383053	−0.06071232
PF 10	0.305037858	0.327638169	0.632676027	0.022600311
PF 11	0.322169067	0.36056747	0.682736536	0.038398403
PF 12	0.335107482	0.486998505	0.822105987	0.151891023

6. Limitations and future directions

Application of PCA is used to factorize the thirty-nine variables into twelve principal factors. The strength of respondents and experts from whom data is collected is restricted to 195 only. The incorporated approach of PCA and Fuzzy DEMATEL is implemented here. This study is restricted to twelve factors whose cumulative probability is also restricted to 82.976 percent. SSIM and other Pair-wise comparison matrices are constructed which are restricted to an expert decision. Experts and respondents having knowledge of BC technology are restricted to the SC field. In this paper, variation in data flow due to barriers like social and climate conditions are not considered. This paper is a nascent step towards the BC technology and every day academician and practitioners are doing their best to improve the SC. This study carried out

Table 7
Direct Normalized Influence Matrix (DNIM).

	PF 1	PF 2	PF 3	PF 4	PF 5	PF 6	PF 7	PF 8	PF 9	PF 10	PF 11	PF 12
PF 1	0	0.0786289	0.0807883	0.0651928	0.0743102	0.0275236	0.0443187	0.1074207	0.0385604	0.0308826	0.0774293	0.0651928
PF 2	0.0100086	0	0.0541559	0.0330419	0.0663925	0.0100086	0.0752699	0.0275236	0.0275236	0.0320823	0.0164867	0.0474379
PF 3	0.0752699	0.0376007	0	0.0143273	0.0253642	0.0088089	0.0376007	0.0774293	0.0364010	0.0088089	0.0474379	0.0596744
PF 4	0.1196572	0.0577549	0.0786289	0	0.0642331	0.0654327	0.0620737	0.0577549	0.0100086	0.0366409	0.0244045	0.0366409
PF 5	0.1196572	0.0320823	0.1074207	0.0697515	0	0.1196572	0.0786289	0.0985433	0.0930249	0.0774293	0.1107798	0.0930249
PF 6	0.0930249	0.0244046	0.0575150	0.0541559	0.0388003	0	0.1230163	0.0419196	0.0330419	0.1074204	0.0596744	0.0541559
PF 7	0.0908655	0.0452785	0.0774293	0.0486375	0.0397601	0.0397601	0	0.0642331	0.0311225	0.0577549	0.0388003	0.0308826
PF 8	0.0486375	0.0275236	0.0896658	0.0287232	0.0265638	0.0330420	0.0863068	0	0.0023307	0.0164867	0.0078492	0.0863068
PF 9	0.0253642	0.0685518	0.0596744	0.01216795	0.00449015	0.0066495	0.0210454	0.0044901	0	0.0155270	0.0155270	0.0188860
PF 10	0.0431191	0.1107798	0.0575150	0.0354413	0.0419195	0.0519966	0.0596744	0.0431191	0.0188860	0	0.0332819	0.0100086
PF 11	0.0865467	0.0519966	0.0774293	0.0476778	0.0599143	0.0232048	0.0443188	0.0577549	0.0244045	0.05776	0	0.0455184
PF12	0.0908655	0.0930248	0.1074207	0.0320823	0.0431191	0.0109683	0.0519966	0.1441303	0.0507969	0.022005	0.0807885	0

Table 8
Total Influence Relation Matrix (TIRM).

TIRM	PF 1	PF 2	PF 3	PF 4	PF 5	PF 6	PF 7	PF 8	PF 9	PF 10	PF 11	PF 12
PF 1	−0.034669	0.060730	0.048641	0.05165	0.058651	0.010723	0.016588	0.084944	0.025450	0.014678	0.062787	0.042411
PF 2	−0.01367	−0.01392	0.035511	0.024118	0.060427	−0.003214	0.065261	0.008695	0.016968	0.022290	0.002394	0.037121
PF 3	0.061849	0.02224	−0.02453	0.002554	0.012910	0.000973	0.023016	0.060218	0.0289406	−0.000692	0.0363386	0.046602
PF 4	0.099546	0.040283	0.053385	−0.018796	0.048035	0.053547	0.038891	0.030410	−0.005365	0.019928	0.001954	0.014362
PF 5	0.077967	−0.00642	0.064265	0.047203	−0.02813	0.107610	0.041915	0.060931	0.078487	0.052416	0.086866	0.066957
PF 6	0.064120	−0.00670	0.025437	0.037116	0.019402	−0.017721	0.107226	0.010884	0.020106	0.094574	0.040748	0.039139
PF 7	0.071211	0.025096	0.054333	0.035722	0.023895	0.028160	−0.023172	0.042430	0.020774	0.046824	0.022819	0.011905
PF 8	0.025197	0.011509	0.071989	0.018347	0.014797	0.025750	0.074880	−0.027702	−0.010019	0.005306	−0.010265	0.077061
PF 9	0.0172352	0.062147	0.052052	0.0068216	−0.00462	0.0040669	0.0121172	−0.0066157	−0.005416	0.0109244	0.0091789	0.0114392
PF 10	0.023939	0.102643	0.037132	0.022815	0.026710	0.043224	0.038577	0.027291	0.008607	−0.015753	0.021272	−0.00843
PF 11	0.065082	0.031748	0.052818	0.034157	0.045258	0.008585	0.023907	0.032582	0.011644	0.047013	−0.01956	0.027341
PF12	0.067390	0.074526	0.076641	0.014922	0.022856	−0.00300	0.024732	0.124302	0.039874	0.007530	0.067641	−0.03041

in the paper motivates industries to implement BC in its SC system. In the future, more than twelve factors can be considered with other restrictions and constraints. The proposed framework in this paper could be used for further research to examine the real casework in any SC. Innumerable experts opinions can be appraised in further research. In the future, the BC integrated SC can be justified by some other quantitative and qualitative methods like ISM, VICKOR, AHP, etc.

Acknowledgement

The research reported in the paper is a part of Research Project (RP03411G) funded by UGC India and UKIERI.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resconrec.2019.104505.

References

Abeyratne, S.A., Monfared, R.P., 2016. Blockchain Ready Manufacturing Supply Chain Using Distributed Ledger.

Ahram, T., Sargolzaei, A., Sargolzaei, S., Daniels, J., Amaba, B., 2017. Blockchain technology innovations. June In: 2017 IEEE Technology & Engineering Management Conference (TEMSCON). IEEE. pp. 137–141.

Anjum, A., Sporny, M., Sill, A., 2017. Blockchain standards for compliance and trust. IEEE Cloud Comput. 4 (4), 84–90.

Azaria, A., Ekblaw, A., Vieira, T., Lippman, A., 2016. Medrec: using blockchain for medical data access and permission management. August In: 2016 2nd International Conference on Open and Big Data (OBD). IEEE. pp. 25–30.

Banerjee, A., 2018. Blockchain technology: supply chain insights from ERP. Advances in Computers Vol. 111. Elsevier, pp. 69–98.

Bashir, I., 2017. Mastering Blockchain. Packt Publishing Ltd.

Bartling, S., Fecher, B., 2016. Could Blockchain Provide the Technical Fix to Solve Science's Reproducibility Crisis? Impact of Social Sciences Blog.

Benchoufi, M., Ravaud, P., 2017. Blockchain technology for improving clinical research quality. Trials 18 (1), 335.

Bhatia, M.S., Srivastava, R.K., 2018. Analysis of external barriers to remanufacturing using grey-DEMATEL approach: an Indian perspective. Resour. Conserv. Recycl. 136, 79–87.

Bitfury Group, 2015. Smart Contracts on Bitcoin Blockchain. Available:. https://bitfury.com/content/downloads/contracts-1.1.1.pdf.

Bogart, S., Rice, K., 2015. The Blockchain Report: Welcome to the Internet of Value. Needham Insights. .

Castillo, Md., 2017. The Lack of Blockchain Talent Is Becoming an Industry Concern. www.coindesk.com/blockchain-hiring-difficulties-becoming-industry-concern/.

Catalini, C., Gans, J.S., 2016. Some simple economics of the blockchain (No. w22952). National Bureau of Economic Research.

Chauhan, A., Kaur, H., Yadav, S., Jakhar, S.K., 2019. A hybrid model for investigating and selecting a sustainable supply chain for agri-produce in India. Ann. Oper. Res. 1–22.

Chiaroni, D., Vecchio, P.D., Peck, D., Urbinati, A., Vrontis, D., 2019. Digital technologies in the business model transition towards circular economy. Resour. Conserv. Recycl. X 2, 100009. https://doi.org/10.1016/j.rcrx.2019.100009.

Chopra, A., 2018. Technology in procurement and supply as prevalent today and scope for future. October In: 2018 International Conference on Automation and Computational Engineering (ICACE). IEEE. pp. 216–223.

Christidis, K., Devetsikiotis, M., 2016. Blockchains and smart contracts for the internet of things. IEEE Access 4, 2292–2303.

Connor, T., 2001. Still Waiting for Nike to Do It: Nike's Labor Practices in the Three Years Since CEO Phil Knight's Speech to the National Press Club.

Dai, J., Vasarhelyi, M.A., 2017. Toward blockchain-based accounting and assurance. J. Inf. Syst. 31 (3), 5–21.

De Filippi, P.D.F., 2018. Blockchain and the Law: the Rule of Code. Harvard University Press.

De Filippi, P., Hassan, S., 2018. Blockchain technology as a regulatory technology: from code is law to law is code. arXiv preprint arXiv: 1801.02507.

Drugs, C.C., 2004. A Report of the Food and Drug Administration. US Department of Health and Human Services Food and Drug Administration, United States of America.

Elder, S.D., Zerriffi, H., Le Billon, P., 2013. Is Fairtrade certification greening agricultural practices? An analysis of Fairtrade environmental standards in Rwanda. J. Rural Stud. 32, 264–274.

Everledger, Sep. 2016. [Online]. Available: http://www.everledger.io.

Fawcett, S.E., Ellram, L.M., Ogden, J.A., 2007. Supply Chain Management: From Vision to Implementation. Pearson Prentice Hall, Upper Saddle River, NJ.

Finch, P., 2004. Supply chain risk management. Supply Chain. Manag. Int. J. 9 (2), 183–196.

Foroglou, G., Tsilidou, A.L., 2015. Further applications of the blockchain. May. 12th Student Conference on Managerial Science and Technology.

Foster, S.T., Ganguly, K.K., 2007. Managing Quality: Integrating the Supply Chain. Pearson Prentice Hall, Upper Saddle River, New Jersey, pp. 256–266.

Gatteschi, V., Lamberti, F., Demartini, C., Pranteda, C., Santamaría, V., 2018. To blockchain or not to blockchain: that is the question. IT Prof. 20 (2), 62–74.

Gunasekaran, A., Patel, C., McGaughey, R.E., 2004. A framework for supply chain performance measurement. Int. J. Prod. Econ. 87 (3), 333–347.

Haber, S.A., Stornetta Jr, W.S. (1992). U.S. Patent No. 5136646. Washington, DC: U.S. Patent and Trademark Office.

Halldórsson, Á., Kovács, G., 2010. The sustainable agenda and energy efficiency: logistics solutions and supply chains in times of climate change. Int. J. Phys. Distrib. Logist. Manag. 40 (1/2), 5–13.

Iansiti, M., Lakhani, K.R., 2017. The truth about Blockchain. Harv. Bus. Rev. 95 (1), 118–127.

Islam, M.S., Tseng, M.L., Karia, N., Lee, C.H., 2018. Assessing green supply chain practices in Bangladesh using fuzzy importance and performance approach. Resour. Conserv. Recycl. 131, 134–145.

Jackson, J.E., Hearne, F.T., 1973. Relationships among coefficients of vectors used in principal components. Technometrics 15 (3), 601–610.

Khatwani, G., Singh, S.P., Trivedi, A., Chauhan, A., 2015. Fuzzy-TISM: a fuzzy extension of TISM for group decision making. Glob. J. Flex. Syst. Manag. 16 (1), 97–112.

King, S., Nadal, S., 2012. PPcoin: Peer-to-Peer Crypto-Currency with Proof-of-Stake. Self-published paper, August 19. .

Koch, B., 2016. E-invoicing/E-billing. Digitisation & Automation, Will.

Korpela, K., Hallikas, J., Dahlberg, T., 2017. Digital supply chain transformation toward blockchain integration. January. Proceedings of the 50th Hawaii International Conference on System Sciences.

Kosba, A., Miller, A., Shi, E., Wen, Z., Papamanthou, C., 2016. Hawk: the blockchain model of cryptography and privacy-preserving smart contracts. May In: 2016 IEEE Symposium on Security and Privacy (SP). IEEE. pp. 839–858.

Kshetri, N., 2018. 1 Blockchain's roles in meeting key supply chain management objectives. Int. J. Inf. Manage. 39, 80–89.

Kumar, A., Dixit, G., 2018. Evaluating critical barriers to implementation of WEEE management using DEMATEL approach. Resour. Conserv. Recycl. 131, 101–121.

Kumar, R., Singh, S.P., Lamba, K., 2018. Sustainable robust layout using big data approach: a key towards industry 4.0. J. Clean. Prod.

Lamba, K., Singh, S.P., 2018. Modeling big data enablers for operations and supply chain management. Int. J. Logist. Manag. 29 (2), 629–658.

Lin, K.P., Tseng, M.L., Pai, P.F., 2018. Sustainable supply chain management using approximate fuzzy DEMATEL method. Resour. Conserv. Recycl. 128, 134–142.

Lucena, P., Binotto, A.P., Momo, F.D.S., Kim, H., 2018. A case study for grain quality assurance tracking based on a Blockchain business network. arXiv preprint arXiv: 1803.07877.

Lundqvist, T., De Blanche, A., Andersson, H.R.H., 2017. Thing-to-thing electricity micro payments using blockchain technology. June In: 2017 Global Internet of Things Summit (GIoTS). IEEE. pp. 1–6.

Luthra, S., Mangla, S.K., 2018. When strategies matter: adoption of sustainable supply chain management practices in an emerging economy's context. Resour. Conserv. Recycl. 138, 194–206.

Luthra, S., Govindan, K., Mangla, S.K., 2017. Structural model for sustainable consumption and production adoption—a grey-DEMATEL based approach. Resour. Conserv. Recycl. 125, 198–207.

Mackey, T.K., Nayyar, G., 2017. A review of existing and emerging digital technologies to combat the global trade in fake medicines. Expert Opin. Drug Saf. 16 (5), 587–602.

Madavi, D., 2019. A Comprehensive Study on Blockchain Technology.

Mangla, S.K., Kusi-Sarpong, S., Luthra, S., Bai, C., Jakhar, S.K., Khan, S.A., 2019. Operational excellence for improving sustainable supply chain performance. Resour. Conserv. Recycl. 142, 277–278. https://doi.org/10.1016/j.resconrec.2018.11.014.

Mathivathanan, D., Kannan, D., Haq, A.N., 2018. Sustainable supply chain management practices in Indian automotive industry: a multi-stakeholder view. Resour. Conserv. Recycl. 128, 284–305.

Michal, J., Cohn, A.L.A.N., Butcher, J.R., 2018. Blockchain technology. Journal.

Mishra, S., Singh, S.P., Johansen, J., Cheng, Y., Farooq, S., 2019. Evaluating indicators for international manufacturing network under circular economy. Manage. Decis. 57 (4), 811–839.

Moore, M., 2012. Mass Suicide' protest at Apple Manufacturer Foxconn Factory. The Telegraph, pp. 11.

Nakamoto, S., 2008. Bitcoin: A Peer-to-peer Electronic Cash System (2008).

Niranjanamurthy, M., Nithya, B.N., Jagannatha, S., 2018. Analysis of blockchain technology: pros, cons and SWOT. Cluster Comput. 1–15.

Nugent, T., Upton, D., Cimpoesu, M., 2016. Improving data transparency in clinical trials using blockchain smart contracts. F1000Research 5.

Opricovic, S., Tzeng, G.H., 2003. Defuzzification within a multicriteria decision model. Int. J. Uncertain. Fuzziness Knowl. Syst. 11 (5), 635–652.

Ølnes, S., Ubacht, J., Janssen, M., 2017. Blockchain in Government: Benefits and Implications of Distributed Ledger Technology for Information Sharing.

Peters, G., Panayi, E., Chapelle, A., 2015. Trends in cryptocurrencies and blockchain technologies: a monetary theory and regulation perspective. J. Finan. Perspectives 3 (3).

Popper, N., Lohr, S., 2017. Blockchain: a Better Way to Track Pork Chops, Bonds, Bad Peanut Butter. New York Times, pp. 4.

Punter, A.D., 2013. Supply chain failures. A Study of the Nature, Causes and Complexity of Supply Chain.

Queiroz, M.M., Wamba, S.F., 2019. Blockchain adoption challenges in supply chain: an empirical investigation of the main drivers in India and the USA. Int. J. Inf. Manage. 46, 70–82.

Rajput, Shubhangini, Singh, S.P., 2018. An Integrated Approach of PCA, ISM and

DEMATEL to model IoT Enablers for Industry4.0", Management decision.
Raju, S., Boddepalli, S., Gampa, S., Yan, Q., Deogun, J.S., 2017. Identity management using blockchain for cognitive cellular networks. May In: 2017 IEEE International Conference on Communications (ICC). IEEE. pp. 1–6.
Rayes, A., Salam, S., 2017. Internet of things—from hype to reality. The Road to Digitization. River Publisher Series in Communications, Denmark, pp. 49.
Rob Price, 2015. This London Startup Could Make Diamond Theft a Thing of the Past — and That's Just the Start. Available:. Business Insider UK. https://www.businessinsider.com.au/everledger-ledger-diamonds-Blockchain-tech-theft-fraud-2015-8.
Saberi, S., Kouhizadeh, M., Sarkis, J., 2018. Blockchain technology: a panacea or pariah for resources conservation and recycling? Resour. Conserv. Recycl. 130, 80–81.
Scherer, M., 2017. Performance and Scalability of Blockchain Networks and Smart Contracts.
Shafagh, H., Burkhalter, L., Hithnawi, A., Duquennoy, S., 2017. Towards blockchain-based auditable storage and sharing of iot data. November In: Proceedings of the 2017 on Cloud Computing Security Workshop. ACM. pp. 45–50.
Smetana, S., Seebold, C., Heinz, V., 2018. Neural network, blockchain, and modular complex system: the evolution of cyber-physical systems for material flow analysis and life cycle assessment. Resour. Conserv. Recycl. 133, 229–230.
Steiner, J., Baker, J., 2015. Blockchain: The Solution for Transparency in Product Supply Chains. https://www.provenance.org/whitepaper.
Sullivan, S., 1999. Human error: bigger problem than disasters. ENT 4 (9), 3.
Swan, M., 2015. Blockchain: Blueprint for a New Economy. O'Reilly Media, Inc.
Tian, F., 2016. An agri-food supply chain traceability system for China based on RFID & blockchain technology. June In: 2016 13th International Conference on Service Systems and Service Management (ICSSSM). IEEE. pp. 1–6.
Tzeng, G.H., Chiang, C.H., Li, C.W., 2007. Evaluating intertwined effects in e-learning programs: a novel hybrid MCDM model based on factor analysis and DEMATEL. Expert Syst. Appl. 32 (4), 1028–1044.
Weber, I., Xu, X., Riveret, R., Governatori, G., Ponomarev, A., Mendling, J., 2016. Untrustedbusiness Process Monitoring and Execution Using Blockchain. International Conference on Business Process Management, Springer International Publishing, pp. 329–347.
Werbach, K., 2018. Trust, but verify: why the blockchain needs the law. Berkeley Tech. LJ 33, 487.
Wüst, K., Gervais, A., 2018. Do you need a blockchain? June In: 2018 Crypto Valley Conference on Blockchain Technology (CVCBT). IEEE. pp. 45–54.
Liang, X., Shetty, S., Tosh, D., Kamhoua, C., Kwiat, K., Njilla, L., 2017. Provchain: a blockchain-based data provenance architecture in cloud environment with enhanced privacy and availability. May In: Proceedings of the 17th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing. IEEE Press. pp. 468–477.
Zhang, C., Wu, J., Zhou, Y., Cheng, M., Long, C., 2018. Peer-to-Peer energy trading in a Microgrid. Appl. Energy 220, 1–12.
Zhu, H., Zhou, Z.Z., 2016. Analysis and outlook of applications of blockchain technology to equity crowdfunding in China. Financ. Innov. 2 (1), 29.
Zyskind, G., Nathan, O., 2015. Decentralizing privacy: using blockchain to protect personal data. May In: 2015 IEEE Security and Privacy Workshops. IEEE. pp. 180–184.