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Modeling the blockchain enabled traceability in agriculture supply chain

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ABSTRACT

Blockchain Technology (BT) has led to a disruption in the supply chain by removing the trust related issues. Studies are being conducted worldwide to leverage the benefits provided by BT in improving the performance of the supply chains. The literature reveals BT to offer various benefits leading to improvements in the sustainable performance of the agriculture supply chains (ASC). It is expected that BT will bring a paradigm shift in the way the transactions are carried in the ASC by reducing the high number of intermediaries, delayed payments and high transaction lead times. India, a developing economy, caters to the food security needs of an ever-growing population and faces many challenges affecting ASC sustainability. It is therefore essential to adopt BT in the ASC to leverage the various benefits. In this study, we identify and establish the relationships between the enablers of BT adoption in ASC. Thirteen enablers were identified from the literature and validated by the experts before applying a combined Interpretive Structural Modelling (ISM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology to envision the complex causal relationships between the identified BT enablers. The findings from the study suggest that, among the identified enablers, traceability was the most significant reason for BT implementation in ASC followed by auditability, immutability, and provenance. The findings of the study will help the practitioners to design the strategies for BT implementation in agriculture, creating a real-time data-driven ASC. The results will also help the policymakers in developing policies for faster implementation of BT ensuring food safety and sustainable ASCs.

1. Introduction

The agriculture supply chain (ASC) is like any consumer product supply chain that includes the suppliers, leading firms, customers, and distribution partners. The primary difference is that either animals or humans consume the final products, and the raw material is grown in farms using agricultural practices (Miranda-Ackerman & Azzaro-Pantel, 2017). In the recent past, the agriculture sector is receiving prominent importance to achieve sustainable growth that is inclusive of best agricultural practices, social well-being of the involved stakeholders and environmental protection (Castro & Swart, 2017; Dentoni & Peterson, 2011). The ASC is under severe pressure from various consumer organizations, social and environmental activists, agro-based companies and policymakers to achieve sustainability (Allaoui, Guo, Choudhary, & Bloemhof, 2018). Luthra, Mangla, Chan, and Venkatesh (2018)) identified a low level of industrialization, inefficient supply chain management, lack of managerial skills and fragmented information sharing leading to low supply chain visibility as the main problems of ASC. Naik and Suresh (2018) claim that to have sustainable development; the ASC should ensure the involvement of farmers and suppliers and take initiatives to meet the stringent food safety and quality regulations. Emerging technologies such as internet of services (IoS), internet of things (IoT) and cloud computing (CC) are supporting the decision making in supply chains leading to performance improvement (Ahumada & Villalobos, 2009). These technologies are helping the ASC to manage the demand-supply variations, stringent food safety norms and other sustainability requirements (Wang & Yue, 2017; Verdouw, Beulens, Reijers, & van der Vorst, 2015). Blockchain technology (BT) is expected to be a significant contributor to the ASC by bringing substantial improvements in the level of accountability, transparency, and traceability by maintaining information power symmetry across all the supply chain partners (Bronson & Knezevic, 2016; Carbonell, 2016). A BT based data management systems in an ASC can act as a significant boost for the sector to manage the land and use records, purchase details and use of farm equipment, seeds, pesticides, traceability and financial transactions across the entire ASC (Maru et al., 2018). These benefits will help the ASC to reduce the increasing cases of product adulteration and frauds thereby, improving sustainability. BT can act as the digital layer providing reliable and trustworthy information on the origin and provenance of farm products

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(Ge et al., 2017).

India is considered as an agrarian powerhouse and is the world's second largest fruits and vegetable producer accounting for 10.9 percent and 8.6 percent of the world fruit and vegetable production (FAO Report, 2017). The Indian ASC face the issue of meeting the demands of the evergrowing population, poor infrastructure used for preserving the horticultural crops, and quality issues leading to annual food losses to the tune of 40 percent (Ritchie, Reay, & Higgins, 2018). The other problems faced by them is the high number of intermediaries leading to delayed payments and high transaction lead times (Balaji & Arshinder, 2016). Furthermore, the consumers are becoming more concern about the product quality and use of safe agricultural practices, thereby putting pressure on the ASC's to adopt responsible sourcing on the agro-based organizations (Yawar & Kauppi, 2018). The current literature on blockchain focuses on the opportunities, benefits, and challenges it offers to the existing supply chain, using literature review methodology (Angelis & Ribeiro da Silva, 2019; Saberi, Kouhizadeh, & Sarkis, 2018; Wang, Han, & Beynon-Davies, 2019; Hughes, Rana, & Dwivedi, 2019; Hughes, Dwivedi et al., 2019).

Further, few studies have focused on analyzing the important behavioral dimensions that affect the blockchain adoption in the supply chain (Kamble, Gunasekaran, & Arha, 2019; Queiroz & Wamba, 2019; Francisco and Swanson, 2018). The supply chain managers, nevertheless are not provided with any decision-making framework on how to adopt blockchain or to inform them about the enablers. As BT is an emerging technology and relatively new in the Indian context it is essential for the practitioners in the ASC to identify the enablers of the BT adoption and understand how they are inter-related with each other and to what extent they can address the above problems. The relationship between the enablers will help the ASC practitioners to convince the organizations to adopt BT in their supply chains to address the issue of sustainability. Therefore, in the present study, we identified factors that enable the BT adoption in the supply chain based on extant literature review and insights received from ASC practitioners. This was followed by the use of a combined interpretive structural modeling (ISM) and decision making trial and evaluation laboratory (DEMATEL) methodology to establish hierarchical levels and relationships between the selected enablers. The findings of the study suggest how the ASC practitioners and policymakers must take important initiatives on enabling a BT driven ASC in India. The remaining of the paper is organized as follows: section 2 presents a literature review on BT, ASC and identifies the enablers of BT. The research methodology is presented in section 3. Section 4 presents the application of ISM-DEMATEL methodology in modeling the enablers of BT in the ASC. Section 5 presents the discussion on the findings and section 6 presents the conclusions, managerial implications, and limitations of the study.

2. Literature review

The researchers carried an extant literature review of articles published in Web of Science and Scopus to get insights on BT adoption in ASCs. The primary search keywords included the terms "blockchain adoption" or "blockchain implementation." The search generated 45 research papers. The second set of keywords were focused on selecting papers that dealt with blockchain in ASC and included the search terms; "blockchain" and "agriculture supply chain" or "food supply chain." The search criteria produced additionally 20 papers. The search was performed in April 2019 without any time restrictions. We also reviewed a few industry reports, news articles, and trade magazines from different internet sources to get additional insights on the selected topic. The review of literature is presented into six subsections viz. overview of BT, the value proposition offered by BT, BT adoption in logistics and supply chain management, BT in the ASC, the BT enablers (BTE) and managerial challenges for BT adoption.

2.1. Blockchain technology

"Blockchain technology" (BT) is becoming one of the most promising technologies of the new economy. Also known as, the "distributed ledger technology," the BT market size is expected to grow to USD 7,683.7 million by 2022, at a compound annual growth rate of 79.6% (Singh, 2018). The vast market potential of BT has taken over the business world by a storm, gaining increased attention from both researchers and industry practitioners (Kamble et al., 2019). BT is expected to transform the traditional ways of performing transactions leading to its applications in a variety of potential areas (Wang et al., 2019). BT employs a distributed (Hofmann, Strewe, & Bosia, 2018; Saberi et al., 2018) and decentralized database (Kouhizadeh & Sarkis, 2018) which is publicly accessible, ensuring a high level of integrity for all the transactions happening on the blockchain network (Nakamoto, 2008). BT is a digital database, which can hold any form of information such as transactions, records, and events with defined rules for information updates (Sikorski, Haughton, & Kraft, 2017). The network continuously grows in the form of blocks, as more transactions (information and data) are added. As the blocks add-on, the system develops and these blocks link and form a chain using a hash. In the context of a data structure, a blockchain network is an ordered list of blocks, which contain transactions, smart-contract creation, and invocations (Nakamoto, 2008). As BT provides a general-purpose programming infrastructure, application specific programs that control the transfer of currencies based on predefined functions or smart contracts can be run on a blockchain network (Ouaddah, Elkalam, & Ouahman, 2017). BT eliminates the role of a third party or an intermediary to control and overlook the system. Instead, it deploys a transparent consensus mechanism which ensures that only valid transactions are executed (Nakamoto, 2008; Bocek & Stiller, 2018). All operations are visible to the participants in the network, and therefore, BT prevents participants' malicious activities.

2.2. The value proposition of Blockchain in supply chains

Supply chain management is defined by the Council of Supply Chain Management Professionals as "the planning and management of all activities involved in sourcing and procurement, conversion and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers" (CSCMP, 2019). Supply chain management is a promising area for BT applications (Kamble et al., 2019). BT adoption in the supply chain enhances visibility and transparency by eliminating trust related issues. The critical factors for any logistics and supply chain organizations are transparency and traceability (Shankar, Gupta, & Pathak, 2018). The primary challenge of the traditional supply chain is the shortage of an open and trustworthy information resource across the supply chain (Wang et al., 2019). Benefits of BT includes the broader participation of stakeholders, lower transaction costs, reduced lead times resulting in increased efficiency. Some of the most prominent features of BT are a consensus mechanism (Nakamoto, 2008), provenance (Kshetri, 2018), auditability (Zheng, Xie, Dai, Chen, & Wang, 2017), immutability (Underwood, 2016), and traceability (Kim & Laskowski, 2018). BT applications are becoming popular across healthcare (Kamble, Gunasekaran, Goswami, & Manda, 2018; Yue, Wang, Jin, Li, & Jiang, 2016), agriculture (Chen, Irawan, & Shae, 2018; Sharma, Kamble, & Gunasekaran, 2018), finance (Hofmann et al., 2018) and Government sectors (Ølnes, 2016). BT application operates without the need for trusted intermediaries ensuring the highest level of cyber-security and privacy (Kshetri, 2017). BT is expected to make the new era supply chains more efficient by making the processes more transparent and reliable, improving the trust related issues in the transactions, which are inevitable in the complex supply chains due to the involvement of multiple partners and presence of finance-related redundancies in

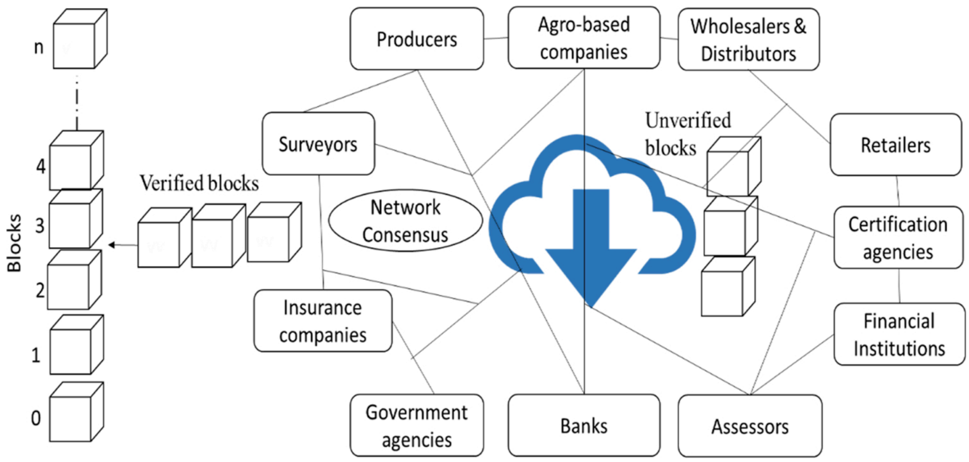

Fig. 1. Blockchain technology in agriculture supply chain.

record keeping (Kim and Laskowski, 2018). Ivanov, Dolgui, and Sokolov (2019)) claim that compared to a traditional supply chain, where higher inventories and excess capacity are maintained in anticipation of supply chain disruptions, the BT driven supply chains help in risk mitigation by efficient management of demand and supply, available supply chain resources and reducing inventory costs.

2.3. Blockchain adoption in supply chain

While many studies in the literature have focused on highlighting the benefits and value derived by the organizations through blockchain implementation, very few studies have analyzed the blockchain adoption behavior at the individual and organizational level. We identified three studies from the literature that analyses the blockchain adoption behavior using survey-based methodologies. These studies are based on the combination of different technology adoption models that included; technology acceptance model, technology readiness index and theory of planned behavior (Kamble et al., 2019), and unified theory of acceptance and use of technology (Francisco & Swanson, 2018; Queiroz & Wamba, 2019). The supply chain practitioners are found to be least concerned about the lack of control or have any distrust on the potential of blockchain because of highly skilled technical employees and experience in supply chain domain (Kamble et al., 2019). The behavioral intention of blockchain adoption is mainly driven by perceived usefulness, and therefore sector wise blockchain applications are required to be developed by the vendors to improve the utility of the blockchain (Kamble et al., 2019). These studies identify that the blockchain adoption by logistics and supply chain management practitioners is still in its nascent stage and there is a need for conducting more sector-specific blockchain adoption studies postulating the relationships between the various enablers and barriers of blockchain adoption. The outcomes of such studies will help the practitioners to understand better the issues and challenges involved in blockchain adoption and formulate strategies to overcome them.

2.4. Blockchain in ASCs

The ASC possess numerous efficiency and transparency problems which cause constant threats to farmers and consumers. Taylor and Fearne (2009) report that there is a constant disconnect between agricultural production and consumer demand because of numerous intermediaries present between producers and consumers. There is also a lack of transparency due to data discrepancies and inconsistencies, lack of interoperability, and lack of information on produce traceability which impacts the ASCs visibility (Wang & Yue, 2017). The agricultural production is dependent on weather and has to deal with difficult situations such as crop diseases and pest infestations, the ASCs are prone to high risk and therefore needs active risk mitigation and control measures. The other issues faced by the ASCs include higher transaction settlement time which is a labor-intensive activity (Pingali et al., 2005), lack of inclusivity of small and medium level farmers which lowers their economic development and makes them ineffective in catering to the demand for surplus food supply from an evergrowing population. By consolidating the links between producers, consumers, farmers, and markets the ASCs can generate higher incomes (Sanghera, 2018).

The ability of BT in product traceability, authenticity, and performing real-time transactions will bring tremendous improvements in food traceability which in turn will have a positive impact on food quality, safety, and sustainability (Li & Wang, 2018; Tian, 2016). BT can reduce risks and increase the efficiency of the ASCs by eliminating intermediaries and ensure transparency and traceability in the ASCs (Yiannas, 2018). The risks and uncertainties can be mitigated by enabling trust among market participants. Smart contracts will help in providing equal opportunities for inclusive market participation for smallholders. BT can integrate and manage all processes and transactions in ASCs on a real-time basis. For all the transactions processed on the distributed ledger, transaction details, and product attributes can be added by the users. Product movements throughout the ASC can be tracked as the product moves from the farmers to the retailers. Fig. 1 presents a schema of a typical blockchain network in ASC.

2.5. Enablers for BT adoption (BTE)

Table 1 contains the list of BTEs identified from the literature. The identified factors represent a summarized and synthesized form of the key BTE's that drives the organizations to implement blockchain in their supply chains. The discussion on the identified enablers is presented below.

2.5.1. Anonymity and privacy (BTE1)

Blockchain has a privacy-preserving framework that allows more information security (Ouaddah et al., 2017; Maesa, Mori, & Ricci, 2017; Zyskind & Nathan, 2015). Blockchain deploys a cryptographic private key which ensures data privacy and anonymity. BT uses ring signatures for providing anonymity of the users in the network. A ring signature is encryption that verifies that the signer, i.e., one of the stakeholders holds a private key that corresponds to a unique set of public keys, without revealing which one (Nakamoto, 2008). BT ensures data security without compromising on the privacy of the stakeholders (Yue et al., 2016).

Table 1
List of BTE's.

BTE	Details	References
Anonymity and privacy (BTE1)	BT deploys cryptographic private key which ensures data privacy and anonymity.	(Nakamoto, 2008; Ying et al., 2018)
Auditability (BTE2)	The blockchain data is error-free and highly visible across the supply chain making it auditable, increasing the auditability and efficiency.	(Atzori, 2015; Hofmann et al., 2018)
Decentralized database (BTE3)	The data is not stored on a single server and is distributed across different nodes.	(MacDonald et al., 2016; Zheng et al., 2016)
Immutability (BTE4)	The transaction data cannot be changed, edited or tampered.	(Tran et al., 2017; Kshetri, 2017)
Improved risk management (BTE5)	Settlement of trade is possible instantaneously, and the dealing parties no longer must worry about failure of payments or trade settlement delays.	(Gokhale, 2016; Wang et al., 2019)
Provenance (BTE6)	Unique digital token assigned for the product at each transaction point in the supply chain.	(Wang et al., 2019; Li & Wang, 2018)
Reduced transaction costs (BTE7)	Compared to traditional supply chains the transaction costs are less due to the removal of intermediaries.	(Iansiti & Lakhani, 2017; Hofmann et al., 2018; Ying et al., 2018)
Reduced settlement lead times (BTE8)	Less number of intermediaries and no requirement for verification by external agencies reduce the lead time.	(Shrier et al., 2016; Kamble et al., 2019; Ying et al., 2018)
Secured database (BTE9)	The data in blockchain data is tamper proof and tough to manipulate.	(Ølnes, 2016; Huckle et al., 2016; Farell, 2015; Chen et al., 2018)
Shared database (BTE10)	Data access is provided to the relevant partners.	(Gokhale, 2016; Wang et al., 2019)
Smart contracts (BTE11)	Electronic contracts with agreed terms and conditions between the parties.	Xu et al., 2016; Nakamoto, 2008.
Traceability (BTE12)	The provenance of data supports the product traceability providing the details on the source of origin of the final product.	(Tian, 2016; Jeppsson & Olsson, 2017; Abeyratne & Monfared, 2016)
Transparency (BTE13)	The data is visible to the concerned parties in real-time and transactions are based on the consensus mechanism.	(Abeyratne & Monfared, 2016; Kshetri, 2017)

2.5.2. Auditability (BTE2)

The blockchain is an auditable, trust-free, tamper-proof, and self-regulating system (Atzori, 2015). Facilitating auditability is one of the most striking features of BT. The provision of a decentralized database makes the blockchain fault- free and helps in maintaining an audit trail (Wijaya, Liu, Suwarsono, & Zhang, 2017). All transactions on the Blockchain are visible to all its participants, with the conforming increase in auditability and trust (Fanning & Centers, 2016). Deploying blockchain across the supply chains will improve accountability, by making the processes trustworthy and guarantee data integrity (Wang et al., 2019). BT can establish an authoritative record for trade data and information which allows organizations to automatically reconcile invoices, which increases accountability and efficiency (Hofmann et al., 2018).

2.5.3. Decentralized database (BTE3)

In a blockchain, the metadata used for communication is scattered throughout the ledger and cannot be collected at one centralized point, i.e., a blockchain database is distributed. The data is not stored on a single server but, is distributed simultaneously on different computers known as nodes. BT uses an open database which enables a decentralized, distributed ecosystem (MacDonald, Allen, & Potts, 2016; Morabito, 2017; Wright & De Filippi, 2015; Zheng et al., 2016). A decentralized database leads to enhanced trust among the participants in a blockchain.

2.5.4. Immutability (BTE4)

Immutability refers to the phenomena that a thing is unchangeable over time or is rather unable to be changed. Immutability enables an audit trail of all the historical operations on the registry to ensure complete traceability of records (Tran, Xu, Weber, Staples, & Rimba, 2017). The blockchain inherently provides an immutable audit trail (Weber et al., 2016) and BTs decentralized nature results in reduced susceptibility to manipulation and forgery of data in the blockchain network by cyber-attacks (Kshetri, 2017).

2.5.5. Improved risk management (BTE5)

Majority of the risks in business processes arise due to delay in payments, inefficient asset management practices, and data threats. With the provision of a distributed database, the final settlement of trade is possible instantaneously, and the dealing parties no longer must worry about failure of payments or trade settlement delays (Gokhale, 2016; Wang et al., 2019). The reduced failure risks will further lead to lower margin or collateral requirements releasing the capital for new investment opportunities. Hence, with the blockchain deployment, decisions on investments and collaterals can be taken quickly instead of following the traditional long-term processes (Micheler & von der Heyde, 2016; Morini, 2016).

2.5.6. Provenance (BTE6)

BT promises better supply chain provenance (Kim and Laskowski, 2018). Some of the industries derive the value of their goods through provenance. Deploying BT will create a unique fingerprint for each of the products. With this, all products can be traced back to their origins throughout the value chain (Wang et al., 2019; Li and Wang, 2018). For deploying blockchain in a supply chain, the blockchains are to be accompanied by digital tokens. At every stage of the value addition process, the stakeholder assigns a digital token to each of the underlying assets. Whenever the underlying asset moves from one stakeholder to the other, the digital token corresponding to that asset is also reassigned in the blockchain. It ensures last mile connectivity as the stakeholders, at any point in time, can track their assets. Secured data provenance is crucial for data accountability (Tosh et al., 2017). Food, music, and art are the major industries where provenance nature of BT can play a significant role (Rabah, 2017).

2.5.7. Reduced transaction costs (BTE7)

BT usage leads to a reduction in transaction costs (Iansiti & Lakhani, 2017). The BT features such as a decentralized database, cryptographic signature protection, and reduced need for intermediaries contribute to the reduction in the transaction costs (Kshetri, 2017). BT also supports reducing the overhead costs as compared to traditional trading practices (Sikorski et al., 2017). The smart contract driven trade transactions helps in the development of a multi-supplier base thereby effectively reducing the transaction costs (Hofmann et al., 2018).

2.5.8. Reduced settlement lead times (BTE8)

BT deployment leads to a reduction in settlement lead-time resulting in a reduction of the transactional lead times. Introduction of BT will result in consolidation or removal of unnecessary steps involved in current post-trade settlement process (Gokhale, 2016). The business processes use the data attributes that are embedded in the transaction making the transaction flow conditional on time, improving the business efficiency by decreasing the transactional lead times (Kamble et al., 2019; Shrier, Wu, & Pentland, 2016; Ying, Jia, & Du, 2018.).

2.5.9. Secured database (BTE9)

BT uses a distributed database. This unique feature of BT makes it highly secure as it uses asymmetrical cryptography and exchange validation in the form of hash and blocks (referred to as mining). The data recorded on a block in the ledger is tough to manipulate. The secured database feature presents a strong case for using it in enabling smart organizations (Chen et al., 2018; Farell, 2015; Huckle, Bhattacharya, White, & Beloff, 2016; Ølnes, 2016; Ying et al., 2018.).

2.5.10. Shared database (BTE10)

The information stored in the ledgers is shared between participants. The participants will have their copy through replication and have restricted access to relevant transactions from the shared system of records (IBM, 2017). The distributed nature of the blockchain network helps to ensure that the transactions do not get compromised from potentially targeted centralized attacks or accidents (Gokhale, 2016; Wang et al., 2019).

2.5.11. Smart contracts (BTE11)

To conduct digital supply chain transactions and document exchanges, stakeholders must agree on coming to a consensus. A smart contract, therefore, comes handy as it contains the agreed terms of stakeholders (Xu et al., 2016). Of late, electronic contracts have made a drastic impact on the business processes, especially in the context of the BT (Scott, Loonam, & Kumar, 2017). Blockchains are secured and apply to a wide range of domains (Bocek & Stiller, 2018). An asset or a currency is transferred into a BT application digitally in the form of a smart contract.

2.5.12. Traceability (BTE12)

BT provides the capability to offer traceability with trusted information, through the process of gathering, sharing, and transferring the authentic data in sourcing, processing, warehousing, distribution and sales (Tian, 2016; Jeppsson and Olsson, 2017). Any information can be traced back to each block of the blockchain via the timestamp (Sharples & Domingue, 2016). The inherited characteristics of BT such as the provision of a secure shared and a decentralized database enhances trust through transparency and traceability for the transaction of goods, data, and financial resources (Abeyratne and Monfared; 2016).

2.5.13. Transparency (BTE13)

In BT, the blockchain network generates an identical copy of the network at each node allowing real-time audit and inspection of the data which brings transparency in the network. Transparency in all the network activities and operations brings high visibility to all the stakeholders in the network thereby reducing the need of a trusted intermediary (Abeyratne & Monfared, 2016). BT can help in bringing transparency to supply chains (), building trust and reputation (Kshetri, 2017; Steiner, 2015). BT provides new frontiers in redesigning the network reputation and helps prevent fraudulent activities (Cai & Zhu, 2016). The consensus in the blockchain paves the way for the high level of authenticity increasing the transparency. Compared to a centralized supply chain, blockchain is far more efficient and transparent (Kamble et al., 2019).

2.6. Managerial challenges for BT adoption

Although, the BT is expected to offer many benefits to the traditional supply chains there are a few challenges the organizations must address. These challenges pose a significant threat to the implementation of BT, as implementing such an emerging system from scratch is a grueling and expensive effort. The experts opine that the organizations should pursue BT adoption when there is a significant expected benefit outweighing the risks compared with their existing centralized technologies. We have categorized these challenges into three categories namely: organizational, technological and environmental.

2.6.1. Organizational challenges

- Resistance from successful organizations to alter their existing revenue models (Michelman, 2017).
- Resistance from existing supply chain intermediaries and other partners, as the blockchain aims to remove the intermediaries (Zhao, Fan, & Yan, 2016).
- Resistance from existing supply chain partners to share valued information in real-time on a decentralized and shared database. (Queiroz & Wamba, 2019; Wang et al., 2019).
- The lack of technical competence and awareness of BT (Kamble et al., 2019). Awareness and expertise are required to be developed on various aspects of BT that includes; application scope, counterparties, process, data, technology, people, regulation, performance, and security (Angelis & Ribeiro da Silva, 2019).

2.6.2. Technological challenges

- The concern that BT can still be hacked by a group of miners coming together referred to as selfish mining (Zhao et al., 2016).
- Huge implementation costs, computing power requirements and environmental concerns because of high energy requirements.
- The blockchain transactions are immutable. However, this will not allow for any corrections in the database, when errors in data entry are committed (Kamble et al., 2019).
- Achieving an optimal combination of interoperable and compatible platforms may be a difficult task (Collomb & Sok, 2016; Wang et al., 2019).
- Issues such as moving from the existing centralized ledger systems (ERP) to a decentralized system and data ownership needs a possible justification in terms of what significant additional benefits the BT will be able to offer (Angelis & Ribeiro da Silva, 2019).

2.6.3. Environmental challenges

- Bringing all the supply chain and trading partners together to implement blockchain across the supply chain network is a difficult task (Kshetri, 2018).
- There is a need to comply with the legal and regulatory framework of Government. Many countries have not yet come with the regulatory guidelines on the same (Kamble et al., 2019). Since the contemporary BT architecture can bypass government interference, revised regulatory and legal restrictions from the government may restrict the value offered by BT.

3. Research methodology

The present study uses combined ISM and DEMATEL decision-making techniques. The basis of the selection and details of the integrated methodology is discussed in this section.

3.1. ISM

Developed by Warfield (1974), ISM is an interactive learning process and is considered as a powerful tool for working with participants in a group where structured debate helps the participants to reach a consensus. ISM assists in structuring and organization a set of different, directly and indirectly, associated elements into a comprehensive systematic model (Sage, 1977). The primary objective of using ISM is to access the domain knowledge of subject experts in disintegrating a complex problem into smaller subsystems leading to the construction of a multi-level structural model (Rana et al., 2018). The emerging

Table 2
Literature on ISM-MICMAC.

Sl. No.	ISM-MICMAC Application Area	References
1	Barriers to m-commerce adoption in SME's.	Rana et al. (2019)
3	Information systems project failure analysis	Hughes, Dwivedi, Rana, & Simintiras, (2016)
4	Mapping information systems failure factors	Hughes, Dwivedi, & Rana (2017)
5	Information systems project success factors	Hughes, Rana, & Dwivedi (2019)
6	Driving innovation through big open linked data	Dwivedi et al. (2017)
7	The trustworthiness of digital government services	Janssen, Rana, Slade, & Dwivedi (2018)
8	Adoption of Industry 4.0 technologies	Kamble, Gunasekaran & Sharma (2018)

Table 3
ISM-DEMATEL application areas.

Sl. No.	DEMATEL Applications	Reference
1	Industry 4.0 applications	Rajput and Singh (2018)
2	e-waste management practices	Kumar and Dixit (2018)
3	Remanufacturing applications	Bhatia and Srivastava (2018)
4	Supplier selection in green SCM	Hsu, Kuo, Chen, & Hu (2013)
6	Critical factors of Green SCM	Wu and Chang (2015)
7	Critical factors for agricultural mechanization development	Bingfu, Zuli, Ming, Zhuojun, & Xiaolian (2008)
8	The value created system of science (technology) park.	Lin and Tzeng (2009)

insights from ISM help in analyzing the inter-relationships and dependence structures between the factors used to illustrate the concept. ISM has been previously used by the researchers to address different problems in the information system context (See Table 2).

Though the ISM methodology has been used extensively for modeling the structural variables, it has a few limitations. The main weakness of ISM is the bias of the person who provides the ratings for the relationship between the variables. The person's knowledge and familiarity with the technology and the industry influence the relationship among the variables (Dwivedi et al., 2017). Dwivedi et al. (2017) list the following steps for deploying the ISM methodology. Similar approaches are used in other research studies (Rana, Barnard, Baabdullah, Rees, & Roderick, 2019; Hughes, Dwivedi, & Rana, 2017; Kamble, Gunasekaran, Goswami et al., 2018; Rana et al., 2018; Kamble, Gunasekaran, Sharma et al., 2018)

i Identification of the variables that influence or has a direct or indirect impact on the system. These variables may be identified from the existing literature or by performing exploratory research studies. However, the defined variables are required to be validated by a group of experts.

ii The experts are required to establish contextual relationships between the variables finalized in the previous step.

iii Development of a structural self-interaction matrix (SSIM) based on the contextual relationships between the pair of variables. The relationships between a pair of variables are denoted by using the alphabets V, A, O, and X.

iv The SSIM is then converted to an initial reachability matrix (IRM). In this step, the alphabets V, A, O, and X are converted to binary elements 0 and 1.

v The IRM is then checked for the presence of transitivity. The transitivity rule states that if a variable P affects variable Q and variable Q affects variable R; then variable P necessarily affects variable Q. Resolving the transitivity leads to the development of the final reachability matrix (FRM).

vi The partitioned levels obtained in the FRM is used to draw a directed graph (DG). The transitivity links are eliminated from the DG, and the contextual links obtained in the IRM are re-established.

vii The variable nodes are then replaced with the statements to convert the DG into an ISM model.

3.2. ISM-DEMATEL

Binary numbers are used in ISM to represent the contextual relationships between the BTEs (0 for no relationship and 1, if a relationship exists). However, in practice, not all the relationships are equal and therefore acts as a significant limitation of the ISM methodology. The relationships may be low, moderate, strong, and very strong (Bhosale & Kant, 2016). In this study, we use DEMATEL methodology to overcome the limitations of ISM and obtain more profound insights into the inter-relationships of BTEs. The results of the DEMATEL are represented through a causal diagram using diagraph, showing the contextual relationships and the strengths of influence between the variables (Shieh, Wu, & Huang, 2010). The DEMATEL methodology has been used in various studies (see Table 3).

Developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972–1979, the DEMATEL methodology analyzes complex and interrelated problems by resolving the cause and effect relationship among the evaluation criteria and establish inter-relationship among factors (Lin and Tzeng, 2009; Kumar & Dixit, 2018). The output of the DEMATEL method is an influence relations map (IRM), a graphical representation of interdependencies within the selected elements.

The procedure for DEMATEL methodology is summarized as follows (Shieh et al., 2010).

3.2.1. Development of direct influence matrix (A)

While developing the A, the diagonal elements of the IRM obtained in ISM are set to zero while the experts are requested to replace the relationships (1's) with 1, 2, or 3 (1= "low influence," 2 = "medium influence," and 3= "high influence." In the A, x_{ij} represents the degree to which factor *i* affected the factor *j*. *I*ndependent matrices, one for each expert ($X^k = [x_{ij}^k]$), where *k* is the expert is developed and a final average matrix ($M = [\, a_{ij}\,]$), *is* computed incorporating the responses of all the *H* respondents as follows:

$$A = 1/H\sum_{k=1}^{H} x_{ij}^k$$

3.2.2. Calculate the normalized initial direct- relation matrix

In this step, the average DIM (A) is normalized to develop an initial direct- relation matrix (D) as follows;

$$D = A \times S;$$

where $S = 1/\ max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}$.

The values obtained in D range from 0 to 1.

3.2.3. Development of total relation matrix

Next, the total relation matrix (T) is developed by using the expression $T = D\,(I - D)^{-1}$, where *I* is the identity matrix. The sum of rows and columns of the total relation matrix is also calculated for computing the degree of influence.

3.2.4. Calculation of the degree of influence

In the total relation matrix, the sum of any ith row (r_i) indicates both

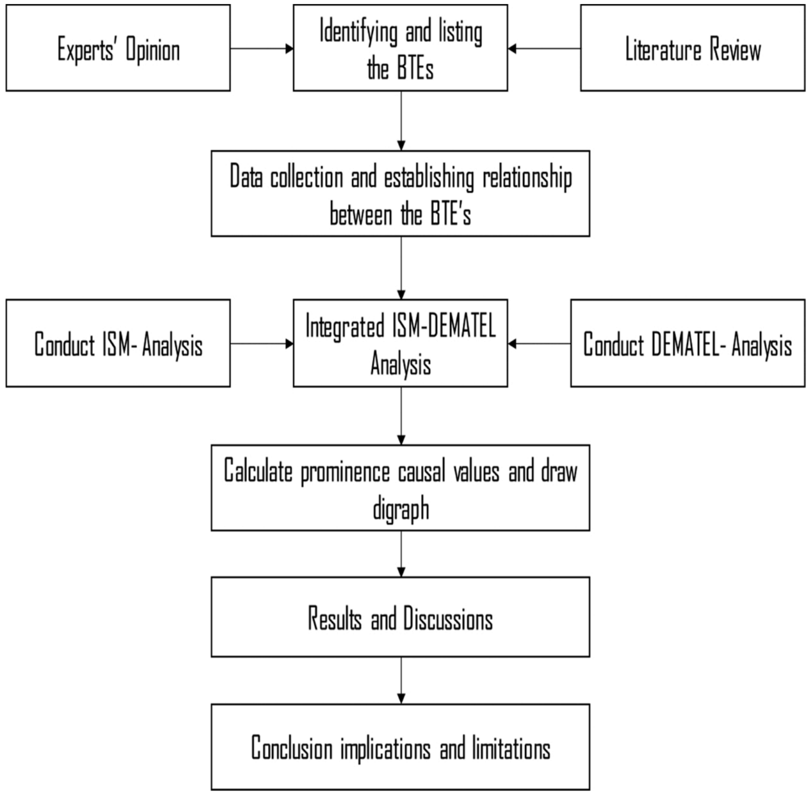

Fig. 2. Framework for research methodology.

direct and indirect effects given by that factor to the other factors. Similarly, the sum of columns of any j[th] column (d_j) indicates both direct and indirect effects received by that factor from the other factors. Therefore, the sum of $r_i + d_j$ indicates the importance of the factor i in the entire system and the difference $r_i - d_j$ indicates the net- effect that factor *i* contributes to the system. The factor i is interpreted as a net cause for positive values of ($r_i - d_j$) and receiver or result when the difference ($r_i - d_j$) is negative.

3.2.5. Digraph plot

In the final step of the DEMATEL, the digraph is plotted using the ($r_i + d_j$) and ($r_i - d_j$) values obtained in the previous step. In order to filter the significant effects, a threshold values is used.

The framework adopted for research methodology is presented in Fig. 2.

4. Application of integrated ISM- DEMATEL methodology for analyzing blockchain enablers in ASC

In this section, we demonstrate the use of ISM and DEMATEL methodology in the context of identifying the BTE's in ASC and establishing the relationships between the identified BTE's.

4.1. ISM methodology

4.1.1. BT enablers for ASC

The BTE for ASC were identified through an extant literature survey and validation from a group of experts. The team of experts consisted of twelve members with the following composition;

i Four academicians: one professor from the supply chain, one professor from computer science, one professor from information technology and one professor from agricultural sciences.
ii Two system integrators with the computer science and engineering background having expertise in the blockchain area.
iii Four senior-level managers from agri-business organizations.
iv Two managers from the banking industry.

The total number of twelve experts satisfied the group size requirements for conducting exploratory studies as suggested by Robbins (1994) and Murry and Hammons (1995). Total of fifteen BT enablers was identified from the literature and discussed with the group of experts for validation. The validation resulted in the final selection of thirteen BTE's for the study. The operational process used to identify these enablers and their description are earlier discussed in Section 2.

4.1.2. Contextual relationships based on ISM hierarchical levels

For analyzing the BTE's in Indian ASC, we use a "leads to" type of contextual relationship structure, which means that one BTE "leads to" another BTE.

4.1.2.1. SSIM development. The SSIM is developed by establishing the contextual relationship between the selected pairs of thirteen BTE's. The same group experts used to validate the BTE's were used for developing the SSIM. As mentioned earlier the following four symbols (V, A, X, and O) were used to define the contextual relationships:

V→ BTE_i will lead to the achievement of BTEj

A→ BTEj will lead to the achievement of BTE_i

X→ BTE_i and BTEj are correlated and hence help to achieve each other.

O→ There exists no relationship between BTE_i and BTEj and are independent of each other.

The SSIM presented in Table 4 is interpreted as follows;

1 The enabler "Secure database technology" (BTE9) leads to the achievement of "Product traceability" (BTE12). Thus, "V" is used to denote the relationship between BTE1 and BTE4.
2 The enabler "Smart contracts" (BTE11) is achieved with the support of "Reduced settlement lead time" (BTE8). Thus, "A" is used to denote the relationship between BTE11 and BTE8.

Table 4
SSIM Matrix.

BTE's	BTE 13	BTE 12	BTE 11	BTE 10	BTE 9	BTE 8	BTE 7	BTE 6	BTE 5	BTE 4	BTE 3	BTE2	BTE1
BTE1	V	V	A	A	A	X	X	V	V	V	A	V	
BTE2	A	V	A	A	A	A	A	X	A	X	A		
BTE3	V	V	V	X	X	V	V	V	V	V			
BTE4	A	V	A	A	A	A	A	X	A				
BTE5	A	V	A	A	A	A	A	V					
BTE6	A	V	A	A	A	A	A						
BTE7	V	V	A	A	A	X							
BTE8	V	V	A	A	A								
BTE9	V	V	V	X									
BTE10	V	V	V										
BTE11	V	V											
BTE12	A												
BTE13													

3 The enablers “Reduced settlement lead time” (BTE8) and “Reduced costs” (BTE7) helps to enable each other. Thus, “X” is used to denote the relationship between BTE7 and BTE8.
4 “O” is used when no relationship exists between the selected BTE's. In our study, “O” was not used signifying that all the selected BTE's either influenced or got influenced by the other BTE's.

4.1.2.2. IRM development. The IRM is prepared by the conversion of the V, A, X and O terms in the SSIM into binary elements (0 and 1). The IRM is shown in Table 5 and is obtained using the following conversion rule:

i If the SSIM entry is “V” for a particular cell (i, j) then in the IRM, the cell (i, j) is replaced by ‘1’ and the corresponding cell (j, i) is entered with the value ‘0’.
ii If the SSIM entry is “A” for a particular cell (i, j) then in the IRM, the cell (i, j) is replaced by ‘0,’ and the corresponding cell (j, i) is entered with the value ‘1’.
iii If the SSIM entry is “X” for a particular cell (i, j) then in the IRM, the cell (i, j) is replaced by ‘1’ and the corresponding cell (j, i) is entered with the value ‘1’.
iv If the SSIM entry is “O” for a particular cell (i, j) then in the IRM, both the cells (i, j) and (j, i) are replaced by ‘0’.

4.1.2.3. FRM development. This step involved the removal of transitivity from the IRM in establishing the level partitions. A MATLAB code was developed and used by the researchers to remove the transitivity. The obtained FRM is presented in Table 6. The partitioned levels obtained in the FRM is then used to draw a directed graph (See Table 7 for the iterations).

4.1.3. ISM-MICMAC analysis

Based on the dependence and the driving power values obtained in FRM in Table 7, the BTE's were classified into four quadrants as shown in Fig. 3. The description of the BTE's in these four quadrants are discussed below;

i Autonomous enablers: The BTEs in this quadrant relates to weak driving and dependence power. The BTEs classified as the autonomous enablers are disconnected from the system and do not have any influence on the adoption of BT in ASC. The findings imply that all the BTEs identified in our study are relevant and play a significant role in enabling the adoption of BTEs in ASC.
ii Dependent enablers: The BTEs in this quadrant relates to weak driving power and strong dependence powers. The dependent enablers are represented in the top upper half of the ISM hierarchical model. In the present study, six BTEs viz., auditability (BTE2), immutability (BTE4), improved risk management (BTE5), provenance (BTE6), traceability (BTE12), and transparency (BTE13) are identified as the dependent enablers. The findings imply that all these six BTEs are considered as the topmost the reasons an organization may consider while deciding to adopt BT in an ASC.
iii Linkage Enablers: The BTEs in this quadrant relates to strong driving and dependence power and are, therefore considered to be unstable. In the present study, no BTE was classified in this category indicating a clear demarcation between two broad categories viz., dependence enablers and driving enablers.
iv Driving Enablers: The BTEs in this quadrant relates to strong driving power and weak dependence power. In the present study, these BTEs are represented in the lower half of the ISM hierarchical model. The BTEs viz., anonymity and privacy (BTE1), decentralized

Table 5
Initial Reachability Matrix.

BTE's	BTE 13	BTE 12	BTE 11	BTE 10	BTE 9	BTE 8	BTE 7	BTE 6	BTE 5	BTE 4	BTE 3	BTE2	BTE1
BTE1	1	1	0	1	1	1	1	1	0	0	0	1	1
BTE2	0	1	0	1	0	1	0	0	0	0	0	1	0
BTE3	1	1	1	1	1	1	1	1	1	1	1	1	1
BTE4	0	1	0	1	0	1	0	0	0	0	0	1	0
BTE5	0	1	0	1	1	1	0	0	0	0	0	1	0
BTE6	0	1	0	1	0	1	0	0	0	0	0	1	0
BTE7	1	1	0	1	1	1	1	1	0	0	0	1	1
BTE8	1	1	0	1	1	1	1	1	0	0	0	1	1
BTE9	1	1	1	1	1	1	1	1	1	1	1	1	1
BTE10	1	1	1	1	1	1	1	1	1	1	1	1	1
BTE11	1	1	0	1	1	1	1	1	0	0	1	1	1
BTE12	0	0	0	0	0	0	0	0	0	0	0	1	0
BTE13	0	1	0	1	1	1	0	0	0	0	0	1	1

BTE1: Anonymity and Privacy, BTE2: Auditability, BTE3: Decentralized Database Technology, BTE4: Immutability, BTE5: Improved Risk Management; BTE6: Provenance, BTE7: Reduced Transaction Costs, BTE8: Reduced Settlement Lead Times, BTE9: Secure Database Technology, BTE10: Shared Database, BTE11: Smart Contracts, BTE12: Traceability, BTE13: Transparency.

Table 6
Final Reachability Matrix.

BTE's	BTE 1	BTE 2	BTE 3	BTE 4	BTE 5	BTE 6	BTE 7	BTE 8	BTE 9	BTE 10	BTE 11	BTE 12	BTE13	Driving Power
BTE1	1	1	0	1	1	1	1	1	0	0	0	1	1	9
BTE2	0	1	0	1	0	1	0	0	0	0	0	1	0	4
BTE3	1	1	1	1	1	1	1	1	1	1	1	1	1	13
BTE4	0	1	0	1	0	1	0	0	0	0	0	1	0	4
BTE5	0	1	0	1	1	1	0	0	0	0	0	1	0	5
BTE6	0	1	0	1	0	1	0	0	0	0	0	1	0	4
BTE7	1	1	0	1	1	1	1	1	0	0	0	1	1	9
BTE8	1	1	0	1	1	1	1	1	0	0	0	1	1	9
BTE9	1	1	1	1	1	1	1	1	1	1	1	1	1	13
BTE10	1	1	1	1	1	1	1	1	1	1	1	1	1	13
BTE11	1	1	0	1	1	1	1	1	0	0	1	1	1	10
BTE12	0	0	0	0	0	0	0	0	0	0	0	1	0	1
BTE13	0	1	0	1	1	1	0	0	0	0	0	1	1	6
Dependence Power	7	12	3	12	9	12	7	7	3	3	4	13	8	100

BTE1: Anonymity and Privacy, BTE2: Auditability, BTE3: Decentralized Database Technology, BTE4: Immutability, BTE5: Improved Risk Management; BTE6: Provenance, BTE7: Reduced Transaction Costs, BTE8: Reduced Settlement Lead Times, BTE9: Secure Database Technology, BTE10: Shared Database, BTE11: Smart Contracts, BTE12: Traceability, BTE13: Transparency.

database technology (BTE3), reduced transaction cost (BTE7), reduced settlement lead time (BTE8), secure database (BTE9), shared database (BTE10), and smart contracts (BTE11) were identified as the driving enablers. The finding implies that these BTEs are the primary enablers that the ASCs sees potential starting points for the BT adoption in ASC.

The ISM hierarchical model is developed using the inputs from the FRM and shown in Fig. 4.

4.2. DEMATEL methodology

4.2.1. Average direct influence matrix

In order to obtain better insights on the causal dependencies and its influence on each other, the DEMATEL methodology was deployed. The same group of experts used for ISM was approached to get the inputs for DEMATEL. The relationships between the BTEs were obtained in a direct influence matrix (A) by using integer scores ranging from 0, 1, 2, and 3 (0 = "no influence," 1= "low influence," 2 = "medium influence," and 3= "high influence"). The average direct influence matrix is shown in Table 8.

4.2.2. Normalized initial direct- relation matrix

In this step, the average direct influence matrix is normalized to develop an initial direct- relation matrix (D), as shown in Table 9.

4.2.3. Total relation matrix

In this step, the total relation matrix (T) was developed by using the expression $T = D\ (I - D)^{-1}$, where I is the identity matrix. We also calculate the sum of rows and columns of the total relation matrix. (See Table 10).

4.2.4. Degree of influence

The sum of $r_i + d_j$ indicates the importance of the BTE i in the entire system and the difference $r_i - d_j$ indicates the net- effect that BTE i contributes to the system. The BTE i is interpreted as a net cause for positive values of ($r_i - d_j$) and receiver or result when the difference ($r_i - d_j$) is negative. The net effect (prominence) values for the BTE's are depicted in Table 11.

4.2.5. Digraph plot

The digraph was plotted using the $r_i + d_j$ and $r_i - d_j$ values obtained in Table 11. In the above digraph, only those effects greater than 0.058 is displayed. The threshold value of 0.58 was computed using the average of all the elements in the matrix T (Shieh et al., 2010).

5. Discussion on the findings

Based on the findings presented in Table 11 and Fig. 5, the selected enablers can be prioritized as follows;

BTE12 > BTE4 > BTE9 > BTE3 > BTE10 > BTE2 > BTE6 > BTE8 > BTE5 > BTE1 > BTE7 > BTE13 > BTE11. The traceability of the agricultural products was found to be the most important enabler (r + d = 1.101). The net cause enablers were; anonymity and privacy (BTE1), decentralized database (BTE3), reduced transaction costs (BTE7), reduced settlement time (BTE8), secured database technology (BTE9), shared database (BTE10) and smart contracts (BTE1). Auditability (BTE2), immutability (BTE4), improved risk management (BTE5), provenance (BTE6), traceability (BTE12) and transparency (BTE13) were identified as the net receivers based on the (r-c) values. It is observed in Table 11 that the BTE12 (traceability) does not affect other enablers but gets affected by all the other enablers. Furthermore, the BTE4 (immutability) and BTE2 (auditability) affects BTE2 (traceability) and gets affected by all the other enablers. Our findings identified the blockchain features such as reduced transaction costs, reduced settlement time, decentralized, secured and shared database as the net cause enablers, supporting the claims made in the previous studies that the BTE's offer supply chain the benefit of disintermediation, enabling integrity of data (Michelman, 2017), no third-party authentications for transactions (Yuan & Wang, 2016) resulting in reduction of transaction costs and settlement lead times (Michelman, 2017). The secured database as a significant enabler supports the claim made in the previous studies enabling trust between the supply chain partners driving the interest in blockchain (Collomb & Sok, 2016; Hull et al., 2017; Nakasumi, 2017). Our findings also support the claim that execution of smart contracts reduces the number of intermediaries leading to reduced costs and transaction delays making the supply chain efficient (Collomb & Sok, 2016; Bocek & Stiller, 2018). These cause enablers were found to influence the net receivers providing real-time visibility of the transactions (transparency) to all the concerned supply chain partners, significantly improving the information available for risk management (Engelenburg, Janssen, & Klievink, 2017; Kshetri, 2017). The information in a blockchain, which is auditable and immutable can help the supply chain to overcome the problems of unethical and illegal exploitation due to its transparency (Collomb & Sok, 2016; Nakasumi, 2017; Weber et al., 2016). Traceability was identified to be the key dependent driver for the blockchain adoption in ASC. The previous research studies indicated that product visibility and traceability is a difficult task to be accomplished in the geographically dispersed and disconnected traditional supply chains. With the consumers paying

Table 7
Iterations for Level Partitions.

Iteration No.	Reachability	Antecedent	Intersection	Level	Iteration No.	Reachability	Antecedent	Intersection	Level
I	1,2,4,5,6,7,8,12,13	1,3,7,8,9,10,11	1,7,8			1,5,7,8,13	1,3,7,8,9,10,11	1,7,8	
	2,4,6,12	1,2,3,4,5,6,7,8,9,10,11,13	2,4,6			1,5,7,8,13	1,3,7,8,9,10,11	1,7,8,	
	1,2,3,4,5,6,7,8,9,10,11,12,13	3,9,10	3,9,10			1,3,5,7,8,9,10,11,13	3,9,10	3,9,10	
	2,4,6,12	1,2,3,4,5,6,7,8,9,10,11,13	2,4,6			1,3,5,7,8,9,10,11,13	3,9,10	3,9,10	
	2,4,5,6,12	1,3,5,7,8,9,10,11,13	5			1,5,7,8,11	3,9,10,11	11	
	2,4,6,12	1,2,3,4,5,6,7,8,9,10,11,13	2,4,6			,5,13	1,3,7,8,9,10,11,13	13	
	1,2,4,5,6,7,8,12,13	1,3,7,8,9,10,11	1,7,8		IV	1,7,8,13	1,3,7,8,9,10,11	1,7,8	
	1,2,4,5,6,7,8,12,13	1,3,7,8,9,10,11	1,7,8,			1,2,3,4,6,7,8,9,10,11,13	3,9,10	3,9,10	
	1,2,3,4,5,6,7,8,9,10,11,12,13	3,9,10	3,9,10			1,7,8,13	1,3,7,8,9,10,11	1,7,8	
	1,2,3,4,5,6,7,8,9,10,11,12,13	3,9,10	3,9,10			1,7,8,13	1,3,7,8,9,10,11	1,7,8,	
	1,2,4,5,6,7,8,11,12	3,9,10,11	11			1,2,3,4,7,8,9,10,11,13	3,9,10	3,9,10	
	12	1,2,3,4,5,6,7,8,9,10,11,12,13	12	I		1,3,7,8,9,10,11,13	3,9,10	3,9,10	
	2,4,5,6,12,13	1,3,7,8,9,10,11,13	13			1,7,8,11	3,9,10,11	11	
II	1,2,4,5,6,7,8,13	1,3,7,8,9,10,11	1,7,8			,13	1,3,7,8,9,10,11,13	13	IV
	2,4,6	1,2,3,4,5,6,7,8,9,10,11,13	2,4,6	II	V	1,7,8	1,3,7,8,9,10,11	1,7,8	V
	1,2,3,4,5,6,7,8,9,10,11,13	3,9,10	3,9,10			1,3,7,8,9,10,11	3,9,10	3,9,10	
	2,4,6	1,2,3,4,5,6,7,8,9,10,11,13	2,4,6	II		1,7,8	1,3,7,8,9,10,11	1,7,8	V
	2,4,5,6	1,3,5,7,8,9,10,11,13	5			1,7,8	1,3,7,8,9,10,11	1,7,8,	V
	2,4,6	1,2,3,4,5,6,7,8,9,10,11,13	2,4,6	II		1,3,7,8,9,10,11	3,9,10	3,9,10	
	1,2,4,5,6,7,8,13	1,3,7,8,9,10,11	1,7,8			1,3,7,8,9,10,11	3,9,10	3,9,10	
	1,2,4,5,6,7,8,13	1,3,7,8,9,10,11	1,7,8,			1,7,8,11	3,9,10,11	11	
	1,2,3,4,5,6,7,8,9,10,11,13	3,9,10	3,9,10		VI	3,9,10,11	3,9,10	3,9,10	
	1,2,3,4,5,6,7,8,9,10,11,13	3,9,10	3,9,10			3,9,10,11	3,9,10	3,9,10	
	1,2,4,5,6,7,8,11	3,9,10,11	11			3,9,10,11	3,9,10	3,9,10	
	2,4,5,6,13	1,3,7,8,9,10,11,13	13			11	3,9,10,11	11	VI
III	1,5,7,8,13	1,3,7,8,9,10,11	1,7,8		VII	3,9,10	3,9,10	3,9,10	VII
	1,3,5,7,8,9,10,11,13	3,9,10	3,9,10			3,9,10	3,9,10	3,9,10	VII
	5	1,3,5,7,8,9,10,11,13	5	III		3,9,10	3,9,10	3,9,10	VII

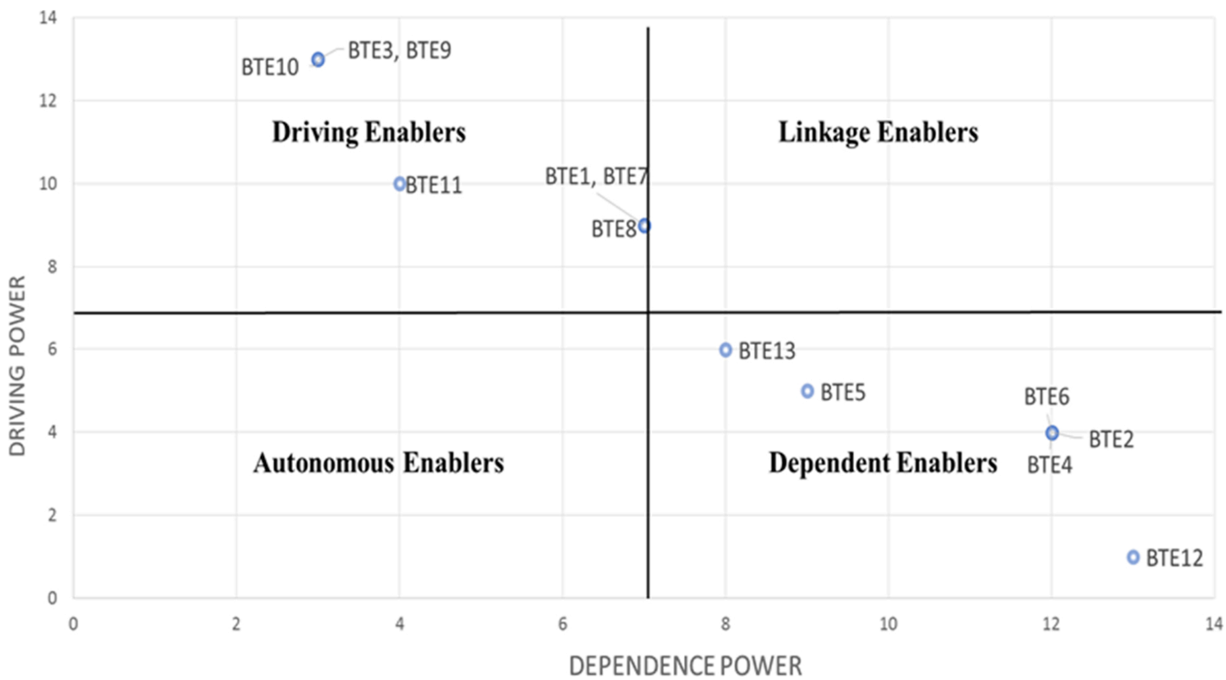

Fig. 3. MICMAC analysis.

more attention to the authenticity and legitimacy of the products they purchase, there is increasing pressure on the ASC's to provide them with the information on the product's origin. The previous studies have identified the blockchain to connect the supply chains seamlessly providing them with a high level of product traceability and visibility (Bonino & Vergori, 2017; Wang and Yue, 2017; Xu, Chen, Gao, Lu, & Shi, 2017; Nakasumi, 2017). Our finding revealed that traceability is the key driving factor for BT adoption in ASC finds strong support in the literature (Tian, 2016; Foerstl, Schleper, & Henke, 2017; Wang et al., 2019).

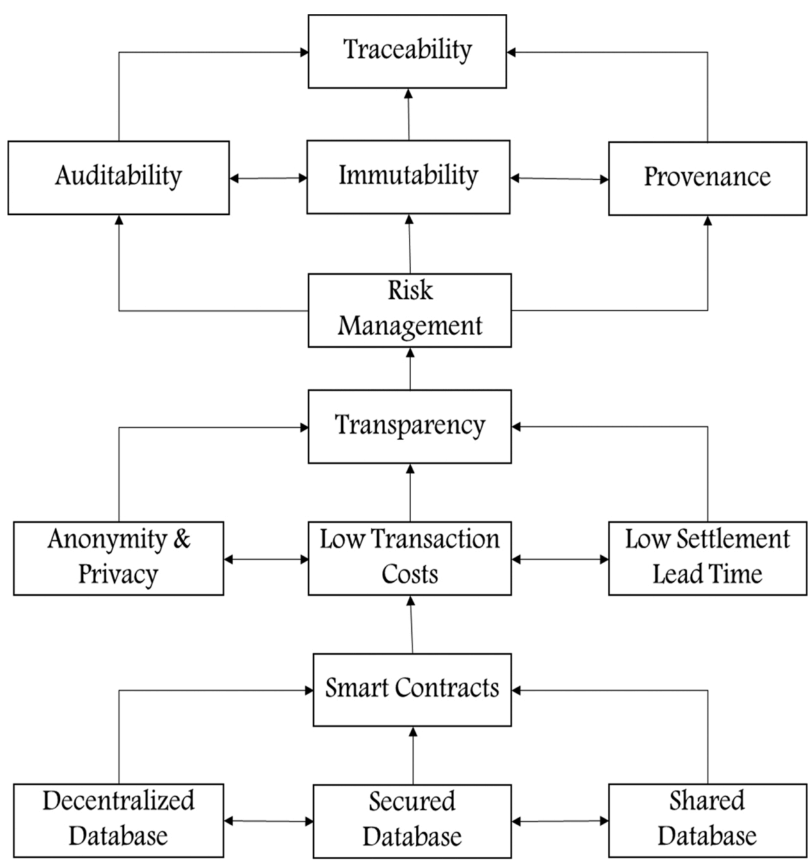

Fig. 4. ISM digraph.

Table 8
Average direct influence matrix.

BTE's	BTE 1	BTE 2	BTE 3	BTE 4	BTE 5	BTE 6	BTE 7	BTE 8	BTE 9	BTE 10	BTE 11	BTE 12	BTE13
BTE1	0.000	2.667	0.000	2.833	1.833	1.833	1.333	1.333	0.000	0.000	0.000	2.833	1.333
BTE2	0.000	0.000	0.000	2.833	0.000	1.000	0.000	0.000	0.000	0.000	0.000	2.667	0.000
BTE3	1.833	2.833	0.000	2.833	1.833	2.833	1.667	1.667	1.333	1.333	1.333	2.833	2.667
BTE4	0.000	1.333	0.000	0.000	0.000	1.500	0.000	0.000	0.000	0.000	0.000	2.833	0.000
BTE5	0.000	1.833	0.000	1.833	0.000	1.833	0.000	0.000	0.000	0.000	0.000	2.667	0.000
BTE6	0.000	1.333	0.000	1.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.833	0.000
BTE7	1.333	1.833	0.000	1.667	1.667	1.833	0.000	1.333	0.000	0.000	0.000	2.833	1.333
BTE8	1.667	1.833	0.000	2.833	2.833	2.500	1.333	0.000	0.000	0.000	0.000	2.833	1.833
BTE9	1.667	2.833	1.333	2.667	2.833	2.500	1.667	1.667	0.000	1.333	1.333	2.667	2.500
BTE10	1.333	2.833	1.333	2.833	2.833	2.500	1.833	1.333	1.333	0.000	1.333	2.833	2.667
BTE11	1.333	1.667	0.000	1.667	2.833	1.667	1.333	1.333	0.000	0.000	0.000	2.833	1.833
BTE12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BTE13	0.000	1.333	0.000	1.667	1.667	1.500	0.000	0.000	0.000	0.000	0.000	2.667	0.000

6. Conclusions, implications, contributions, and limitations of the study

BT is in its nascent stage, and there are numerous challenges-technical, regulatory, infrastructural, and institutional which BT needs to overcome before reaching its maturity stage. The other challenges include enormous computing power and high bandwidth internet connection, which requires enormous efforts from implementing organizations to acquire them in a short time (Min, 2019). BT holds tremendous potential in leveraging ASC operations if the enablers to its adoption are reinforced with favorable strategies and policies. The enablers of BT in ASC were identified from the literature, validated by the experts before using the ISM and DEMATEL methodology to establish the dependency relationships between them. In this section, we discuss the implications for managers and policymakers and highlight the limitations of the study.

6.1. Managerial implications

The findings of this study offer meaningful insights to practitioners in the agribusiness organizations, consultants and blockchain system integrators while implementing BT in the ASCs. The knowledge of dependent and the driving enablers identified from the ISM will be highly useful for the practitioners to take care of the implementation challenges of BT in ASC. In this study, driving enablers define the performance outcome of BT. DEMATEL technique uncovered the prominence-causal relationships amongst the BT enablers, by categorizing the BTEs in cause and effect groups. This will enable the practitioners to focus on the causal effects of the enablers in BT adoption and will guide them for faster implementation of BT in ASCs.The findings suggest that the practitioners should pay more attention to the identified causes (BTE1, BTE3, BTE7, BTE8, BTE9, BTE10, and BTE11) rather than the receivers (BTE2, BTE4, BTE5, BTE6, BTE12, and BTE13). The (r + c) and (r-c) value implies that a decentralized database (BTE3) which is sharable (BTE10) and secured (BTE9) are the critical enablers of the BT in ASC. These enablers than helps the ASCs in achieving reduced settlement lead times (BTE8) with reduced transaction costs (BTE7) with the help of smart contracts (BTE11) that eventually will result in achievement of a blockchain environment which is auditable (BTE2), immutable (BTE4), provides provenance (BTE6), improves risk management (BTE5), transparent (BTE13) and traceable (BTE12). The findings of the study imply that the ASC pursues substantial benefits from the blockchain technology and therefore, the practitioners are required to acquire capabilities required to use the technology. The practitioners will be required to overcome the challenges of taking their stakeholders along with and includes overcoming the fear of losing revenue models (Michelman, 2017), banks reluctance to support blockchain enabled transactions (Zhao et al., 2016), resistance from intermediaries because of the fear of being removed and supply chain partners aversion from sharing information (Fawcett, Osterhaus, Magnan, Brau, & McCarter, 2007; Kembro & Näslund, 2014). The findings of the study imply that the practitioners are highly inclined to have a good traceability system so that their ASC produces safe and high-quality products, thereby resulting in a good brand image and trust. The food falsification has become a significant issue for all the stakeholders involved in an ASC that includes the producers, researchers, governments, and consumers. The existing practices of food labeling systems fall short of providing the customers the confidence of buying authentic, safe and quality product. The findings identified the increasing importance of tracking and authenticating the food supply chain to understand provenance and need

Table 9
Normalized initial direct relation matrix.

Enablers	BTE 1	BTE 2	BTE 3	BTE 4	BTE 5	BTE 6	BTE 7	BTE 8	BTE 9	BTE 10	BTE 11	BTE 12	BTE13
BTE1	0.000	0.107	0.000	0.113	0.073	0.073	0.053	0.053	0.000	0.000	0.000	0.113	0.053
BTE2	0.000	0.000	0.000	0.113	0.000	0.040	0.000	0.000	0.000	0.000	0.000	0.107	0.000
BTE3	0.073	0.113	0.000	0.113	0.073	0.113	0.067	0.067	0.053	0.053	0.053	0.113	0.107
BTE4	0.000	0.053	0.000	0.000	0.000	0.060	0.000	0.000	0.000	0.000	0.000	0.113	0.000
BTE5	0.000	0.073	0.000	0.073	0.000	0.073	0.000	0.000	0.000	0.000	0.000	0.107	0.000
BTE6	0.000	0.053	0.000	0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.073	0.000
BTE7	0.053	0.073	0.000	0.067	0.067	0.073	0.000	0.053	0.000	0.000	0.000	0.113	0.053
BTE8	0.067	0.073	0.000	0.113	0.113	0.100	0.053	0.000	0.000	0.000	0.000	0.113	0.073
BTE9	0.067	0.113	0.053	0.107	0.113	0.100	0.067	0.067	0.000	0.053	0.053	0.107	0.100
BTE10	0.053	0.113	0.053	0.113	0.113	0.100	0.073	0.053	0.053	0.000	0.053	0.113	0.107
BTE11	0.053	0.067	0.000	0.067	0.113	0.067	0.053	0.053	0.000	0.000	0.000	0.113	0.073
BTE12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BTE13	0.000	0.053	0.000	0.067	0.067	0.060	0.000	0.000	0.000	0.000	0.000	0.107	0.000

BTE1: Anonymity and Privacy, BTE2: Auditability, BTE3: Decentralized Database Technology, BTE4: Immutability, BTE5: Improved Risk Management; BTE6: Provenance, BTE7: Reduced Transaction Costs, BTE8: Reduced Settlement Lead Times, BTE9: Secure Database Technology, BTE10: Shared Database, BTE11: Smart Contracts, BTE12: Traceability, BTE13: Transparency.

Table 10
Total relation matrix.

BTE's	BTE 1	BTE 2	BTE 3	BTE 4	BTE 5	BTE 6	BTE 7	BTE 8	BTE 9	BTE 10	BTE 11	BTE 12	BTE13	Row total
BTE1	0.007	0.140	0.000	0.156	0.088	0.109	0.057	0.057	0.000	0.000	0.000	0.183	0.061	0.857
BTE2	0.000	0.009	0.000	0.117	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.124	0.000	0.297
BTE3	0.094	0.191	0.006	0.207	0.125	0.189	0.088	0.087	0.057	0.057	0.060	0.250	0.139	1.550
BTE4	0.000	0.057	0.000	0.010	0.000	0.063	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.255
BTE5	0.000	0.082	0.000	0.087	0.000	0.082	0.000	0.000	0.000	0.000	0.000	0.131	0.000	0.383
BTE6	0.000	0.057	0.000	0.060	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.087	0.000	0.209
BTE7	0.057	0.105	0.000	0.107	0.082	0.104	0.006	0.057	0.000	0.000	0.000	0.173	0.061	0.752
BTE8	0.070	0.115	0.000	0.161	0.128	0.139	0.057	0.007	0.000	0.000	0.000	0.192	0.081	0.950
BTE9	0.088	0.192	0.057	0.202	0.162	0.178	0.087	0.086	0.006	0.057	0.060	0.244	0.133	1.552
BTE10	0.075	0.190	0.057	0.205	0.160	0.176	0.092	0.073	0.057	0.006	0.060	0.249	0.138	1.538
BTE11	0.061	0.108	0.000	0.118	0.134	0.108	0.060	0.060	0.000	0.000	0.000	0.190	0.084	0.922
BTE12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BTE13	0.000	0.067	0.000	0.083	0.067	0.073	0.000	0.000	0.000	0.000	0.000	0.136	0.000	0.424
Column Total	0.452	1.313	0.12	1.513	0.946	1.274	0.447	0.427	0.12	0.12	0.18	2.084	0.697	9.693

BTE1: Anonymity and Privacy, BTE2: Auditability, BTE3: Decentralized Database Technology, BTE4: Immutability, BTE5: Improved Risk Management; BTE6: Provenance, BTE7: Reduced Transaction Costs, BTE8: Reduced Settlement Lead Times, BTE9: Secure Database Technology, BTE10: Shared Database, BTE11: Smart Contracts, BTE12: Traceability, BTE13: Transparency.

Table 11
Prominence causal values.

BTE's	d_j	r_i	$r_i + d_j$	$r_i - d_j$
BTE1	0.452	0.857	1.309	0.405
BTE2	1.313	0.297	1.610	−1.016
BTE3	0.119	1.550	1.669	1.431
BTE4	1.514	0.255	1.769	−1.259
BTE5	0.947	0.383	1.330	−0.564
BTE6	1.273	0.209	1.482	−1.064
BTE7	0.448	0.752	1.200	0.304
BTE8	0.426	0.950	1.376	0.524
BTE9	0.119	1.552	1.671	1.433
BTE10	0.119	1.538	1.657	1.419
BTE11	0.179	0.922	1.101	0.743
BTE12	2.084	0.000	2.084	−2.084
BTE13	0.696	0.424	1.120	−0.272

BTE1: Anonymity and Privacy, BTE2: Auditability, BTE3: Decentralized Database Technology, BTE4: Immutability, BTE5: Improved Risk Management; BTE6: Provenance, BTE7: Reduced Transaction Costs, BTE8: Reduced Settlement Lead Times, BTE9: Secure Database Technology, BTE10: Shared Database, BTE11: Smart Contracts, BTE12: Traceability, BTE13: Transparency.

for a high level of traceability (Aung & Chang, 2014; Galvez, Mejuto, & Simal-Gandara, 2018). The findings imply the acceptance of BT as an innovative tool to ensure an efficient ASC by the practitioners. The practitioners agree that their ASC can realize traceability with trusted information sources by collecting authentic real-time data of agriculture produce, food processing, storage, food distribution and retailing enabled by a BT platform. The practitioners should aim to develop strong technical partnerships with leading BT service providers and system integrators to build traceability capability for the organizations. The findings reveal that to achieve traceability; there is a requirement of a robust technology platform that is secured, sharable, enabled by smart contracts and decentralized. Such partnerships will be able to develop a world-class traceability capability. The practitioners will be required to adopt lean supply chain principles to support information management during a digital product lifecycle (Vazquez-Martinez, Gonzalez-Compean, Sosa-Sosa, Morales-Sandoval, & Perez, 2018).

Further to achieve traceability at the global scale, the ASC should ensure that the BT deployed at their organizational level has mapped all the critical transactions as per the existing international standards and are validated. The practitioners should aim at capturing all the relevant information about the entire cycle of agricultural events onto the blockchain to enable the transparent and trusted source of information for the farmers. This will support the farmers and all the other stakeholders to have data related to the seed quality, soil moisture, climate, payments, demand and sale price, etc. on one single platform. With BT, the practitioners will be able to achieve a direct link between the food producers and the final consumers. The BT initiatives will help to empower the small farmers to organize themselves, eliminating the requirement of intermediaries.

Further, the enablers identified in this study provides an opportunity for the stakeholders to quantify, monitor, and control the risks in

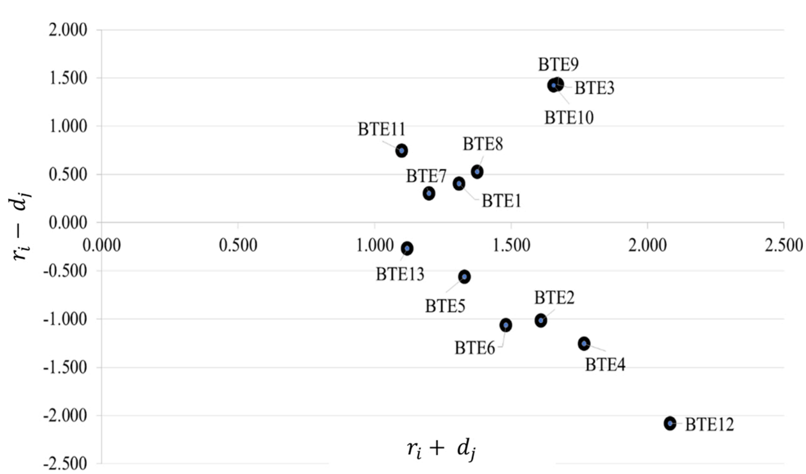

Fig. 5. Prominence causal diagram.

the ASCs, relieving the rural distress and social sustainability in developing countries like India. For this to happen, the practitioners should include and integrate the technical benefits to be achieved from BT with a social perspective. The BT enabled ASC should provide opportunities to its supply chain partners with appropriate incentives to capture complete, and reliable data, which is a requirement for achieving traceability of the farm produce.

6.2. Implications for policymakers

For the policymakers, implementation of BT in ASC will ease the regulatory and certification norms as the agricultural products can be traced along with each phase. This will reduce fraudulent activities in the ASCs and result in accountability of the processes. For ensuring tamper-proof transactions, appropriate origin labeling, RFID tags, safe packing, and a secure network of integrated intermediaries needs to be developed. Traceability details will boost food quality, safety and help in maintaining quality control throughout the ASC. Transparency in ASC will ensure that food quality compliance is met and will lead to improved product sustainability standards. BT will help facilitate international trade by meeting the necessary sanitary and phytosanitary standards (SPS). As produce data about quality, safety, and sustainability would be available on the blockchain network, cases of any food related contamination and safety issue can be quickly traced. BT will help in determining the origins of the contaminated product and thereby ensuring that faulty produced is removed from the warehouse thereby minimizing health and financial losses. The existing trade finance methods are complicated, time-consuming, inefficient, and involve much paperwork for managing transactions. This hurts businesses and hampers the cash-flow and working capital requirements. The study identified BT to reduce the transaction cost times, settlement lead times, risks for stakeholders, and efficient transactions processes. BT will ensure real-time approvals and payments in trade finance. Transparency in transactions will be maintained as all information would be available and accessible to all stakeholders across the blockchain network. Implementing BT will bring in greater auditability and accountability in the transaction processes.

Financial services such as agriculture value chain credit and insurance services also play a crucial role in reducing the stakeholders' risk. BT can help in financial inclusion of small land holding farmers by enhancing the efficiency of the ASCs. Smart contract enabled services on BT can assist the stakeholders in eliminating unnecessary human interventions which lead to payment delays. Implementing BT will help in ensuring data integrity and improved visibility of the ASC. BT can serve as the foundational technology which can integrate, accommodate, and cooperate with other emerging technologies into its network thereby improving the ASC continuously. Techniques such as IoT, artificial intelligence, 3-D printing can help in realizing data-driven ASCs.

Furthermore, in India, the Government supports the agriculture sector by providing high levels of subsidy. The budgeted subsidies for the year 2017-18 was USD 4.9 billion (INR 32,000 Cr) however, there is no proper mechanisms that exist today on evaluating the transparency of the disbursement process and to know what proportion of these subsidies have reached to the targeted beneficiaries. Adoption of BT can ensure a more transparent system of distribution and delivery of the subsidies removing the pilferage points in the system. The policymakers in India should consider all the above enablers of BT and the dependency relationships between them while designing the BT policy for the Indian agriculture sector.

6.3. Contributions of the study

The primary objective of this paper was to identify the enablers that encourage the blockchain adoption in ASC and to establish the causal relationship between them. The study contributes to the theory in several ways. First, this research has compiled all relevant studies on blockchain adoption, reviewed and synthesized the literature to extract enablers of blockchain adoption in ASC context. Second, this is the first research of its type that has explored the enablers of BT adoption and derived its framework using a combined ISM and DEMATEL methodology for the ASCs in the context of India. Third, the driving and dependence powers of the BTEs using the MICMAC diagram and the magnitude of the relationships using the DEMATEL is expected to help the practitioners and researchers to clearly understand and categorize the BTEs as independent, mediating or dependent variable. Finally, the developed framework using ISM and DEMATEL will help the researchers to select the relevant variables and develop new research models.

6.4. Limitations and future directions

The study identified thirteen enablers for implementing blockchain technology in agriculture supply chains. The enablers were identified from existing literature and validated by experts from the field of agro-based supply chain and technology. The selected experts were from India, and they might have been missed on a few blockchain technology enablers, that would have been significant in another countries context. Therefore, it is recommended to conduct similar studies on enabling blockchain technology in other countries and explore new enablers that may have an impact on the blockchain technology adoption. The outcomes of such studies should be compared with the results obtained in this study and used for refining the interdependencies between the enablers. It would be interesting to conduct similar studies in developed economies as the agricultural practices in these countries are technologically advanced, with few countries already in the stage of implementing blockchain technologies in agriculture supply chains.

Further, the ISM-DEMATEL methodology used subjective judgments from academicians, practitioners and system integrators to establish the interdependencies between the selected blockchain enablers. Even though the researchers took enough care, the personal biases of the chosen experts may have influenced the outcomes of the study. Future studies may be conducted on validating the cause-effect relationships obtained in this study using empirical research designs based on survey methodology. We recommend the use of Structural Equation Modeling (SEM) and other multicriteria decision-making tools for this purpose.

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