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INFORMATION PROCESSING IN AGRICULTURE 8 (2021) 398–408

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

# A blockchain maturity model in agricultural supply chain

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A R T I C L E I N F O

*Article history:*
Received 29 May 2020
Received in revised form
10 October 2020
Accepted 22 October 2020
Available online 10 November 2020

*Keywords:*
Blockchain
Agricultural supply chain
Maturity model
SWARA

A B S T R A C T

Blockchain technology is a disruptive technology that changes business and supply chain models. Using distributed software architecture and advanced computing, blockchain can change the way information is exchanged between actors in the chain. Blockchain technology provides a platform for solving the problem of tracking product information in supply chain management. Accordingly, the present study aims to provide a model for evaluating the maturity of blockchain technology in the agricultural supply chain. The present research is applied that has been done in three stages. In the first phase, the dimensions of the blockchain are ranked by agricultural experts using the SWARA method. The research experts are 13 faculty members of the department of agriculture active in the field of technology application. In the second phase, a model is designed to evaluate blockchain maturity using each dimension of blockchain technology and maturity dimensions. In the third phase, the proposed model is tested using data collected by a questionnaire in the supply chain of a company active in the agriculture sector. The research findings show that smart contracts, Internet of Things (IoT), and transaction records are of the highest importance among the blockchain dimensions. Also, the supply chain under study is in a good condition in digital documents. Theoretically, the originality aspect of the research is that it determines the importance of blockchain dimensions in the field of agriculture and from an applied point of view, it introduces the maturity model of blockchain in supply chain management.



## Contents



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Peer review under responsibility of China Agricultural University.
https://doi.org/10.1016/j.inpa.2020.10.004
2214-3173 

## 1. Introduction

Supply chain refers to the design, engineering, production and distribution processes of goods and services from suppliers to customers [1]. Because these processes affect the flow of goods, information and finance, laws and regulations are enacted to protect the rights of individuals and customers. For example, the United Nations has enacted laws on the protection of security, information, health, and compensation [2]. Supply chains are typically under centralized management systems, such as enterprise resource planning systems for information flow management. Such systems are prone to error, hacking, and corruption. Blockchain technology, an emerging smart technology, can effectively manage these issues. This is a digital, decentralized and disruptive innovation in which transactions are recorded in chronological order with the aim of creating permanent and anti-monopoly records [3]. Blockchain technology is a distributed ledger that shares all network transactions between members. All network transactions in the form of timestamped block must be approved by most members and nodes of the network before performing any activity [4]. Before adding a data block to the network, its members must agree on the content of the data block and its relationship with the previous blocks [5].

Given that the blockchain technology can transform many of the supply chain's activities and operations, there is a need for the attention and participation of researchers and executives in this area [6]. In fact, the increasing use of new technologies, such as IoT and artificial intelligence programs, will affect supply chain management [6–8]. Blockchain technology allows goods and individuals to be tracked from their origin throughout the supply chain based on real time. The blockchain technology also gives all supply chain operators the ability to know what was done at what time and by whom [9]. Interpersonal and inter-organizational communication using the blockchain distributed system is more reliable [10]. To create a successful network, it is necessary to create a platform for different organizations and sectors to ensure the creation, storage and distribution of their files. For example, financial centers, banks, insurances, education, and medical and health centers may be involved in many services of various industries, and the flow of secure information between these sectors and the supply chain is very important. The blockchain network is a good way to prevent corruption and human error [11]. Another advantage of blockchain technology in the supply chain is the management of individuals' identity and the correct identification of activities performed. Various studies have addressed blockchain capabilities, such as transparency, accountability, secure data, cost reduction, and effective manufacturing processes in various contexts, such as aviation, transportation, agriculture and food [12–16]. Identifying the applications and specialized challenges of each field paves the way for the effective use of this technology. Agriculture had always been a major strategic activity for supplying food. In 2018 more than 821,000,000 people were suffering malnutrition worldwide and each year more than 10,000,000 people die of starvation [17]. Moreover, agriculture has always faced with the prevailing challenges of food security, food safety, sustainable development and health. Agri-food supply chain has been studied many times in previous studies. In the early and mid-twentieth century the applied techniques for confronting these challenges were non-digital. Although industrial agriculture was developed to be responsive to the challenges, it had its own inherent challenges of low resource efficiency, climatic changes, animal exploitation and healthy life style of the consumers [18–20]. The use of disruptive technologies, such as artificial intelligence, IoT, and the blockchain will improve the performance of businesses in agriculture. The use of blockchain technology in the agri-food supply chain makes it possible to track the product accurately and transparently from the time of production to the time of delivery to the consumer. Blockchain technology also gives access to reliable information to all stakeholders in the Agri-food supply chain [1–4]. Other applications of blockchain technology in the agri-food supply chain include smart contracts and decentralization of information in the network. Xu et al. [20] believe that the use of blockchain improves the security and quality of agri-foods in four ways: enhance the data transparency, realize data traceability, improve the food safety and quality monitoring, and reduce the cost of financial transactions.

Studies on the applications of blockchain technology in agriculture, such as Tian [21], Mirabelli and Solina [22], show the importance of this technology and its capabilities in agriculture and food industry. However, there is a research gap in assessing the progress and maturity of this technology in agriculture and there is a need for a study that provides a tool and a model to evaluate the development and maturity of blockchain in the field of agriculture. Another innovation of this research is to determine the importance and priority of blockchain dimensions in agriculture. Previous studies have described the dimensions of blockchain, but prioritizing these dimensions for planning and investment is important for managers and policymakers in the field of agriculture. Therefore, the main issue of this research is to determine the importance of each dimension of the blockchain and provide a model to assess the maturity of this technology in the agriculture sector. the research questions are:

1. How is the prioritization of blockchain technology dimensions in the agricultural supply chain?
2. How can blockchain technology maturity be assessed?

## 2. Literature review

### 2.1. Blockchain

The blockchain was first introduced as a platform for the digital currency of Bitcoin. The Bitcoin network is also the largest and oldest blockchain network in the world. Today, blockchain technology is not only a platform for cryptocurrencies, but also has many applications and advantages [23]. The blockchain technology is based on the distributed ledger. A distributed ledger is a database that is updated independently by each participant (or node) on a large network [24]. The distributed database indicates its publicity; In this case, the files are not transferred to different nodes by a central authority, but are created and maintained independently by each node (computer). However, blockchain can maintain security as each transaction is verified by using public–private-key cryptography, and the transaction records on the blocks cannot be modified once they are accepted as parts of the table chain because they are attached to each other [25]. The blockchain technology has played a significant role in a variety of business and social interactions due to transparency, security, and performance improvement [26].

In a blockchain system, each data block is identified by a hash encryption function and interacts with other blocks, forming a data blockchain [27]. Accordingly, the blockchain technology reduces the role of intermediaries that cause disruption, hacking, and fraud. When the blockchain technology is used, trust in the network and its operations is increased [28]. This technology makes it possible to create and transfer digital assets with high confidence. Another feature of this technology is the smart contract module, which stores the negotiation terms and confirms the results against the agreed terms. This reduces the role of intermediaries, increasing transparency in transactions and interactions [29]. These blockchain capabilities are also used in a supply chain

### 2.2. Blockchain and supply chain management

Over the past few years, research has been conducted in the field of supply chain management and the use of disruptive technologies, such as big data, IoT, cloud computing, and blockchain [30,31]. The distributivity of the blockchain network promotes transparency and tracking of goods and services in a supply chain. These capabilities require accurate data collection and secure storage for reliable data tracking.

The goal of a proper tracking system is to reduce poor quality goods and unreliable distribution using proper labeling and accurate tracking. Today, traditional tracking systems have become automated controls by IoT technology [32,33]. The main components of a tracking system include the tag, the tracer, and the sensor. Tag is a label that is inserted on the product and the product package and by which the product is identified. Radio-frequency identification (RFID) and Quick Response Code (QR Code) systems are examples of a tagging system. A tracer is a substance that is placed in a commodity or is a natural property of a commodity that provides information about the process of production and the confirmation of the quality of a commodity. The sensor is a tool that detects environmental changes, such as light, sound, humidity, pressure, and temperature. Sensor information is sent to other tools and equipment on the network [5]. Using blockchain technology, the information transmitted by the sensors, such as product information, pricing, and the production process, is approved by various nodes in the network, thus providing high reliability of the information. Helo et al. [34] point to the limitations of Enterprise Resource Planning (ERP) systems, including their centrality, and provide cloud-based information systems. Cloud computing technology provides a platform and infrastructure that allows the exchange, storage and monitoring of information. In fact, a centralized virtual database replaces a centralized physical database, with the same challenges of privacy and information security in this technology. There is no discussion of decentralization, and the cloud information system may be attacked and hacked [35]. The use of blockchain technology has solved the problem of information centralization and access to information due to the use of distributed systems.

Kshetri [6] classified data stored in a blockchain in a supply chain into five categories:

Digital Documents: In this case, paper documents must be converted to digital files, which reduces the cost of data transfer and management. Digital documents speed up the process of information approval and flow in the supply chain.

Internet of Things (IoT): IoT technology is an important platform for tracking goods. The development of IoT technology has made it possible for many objects to connect to the Internet to communicate with each other without human intervention. In essence, IoT reduces human data entry and uses a variety of sensors to collect data from the environment, allowing automated storage and processing of all data [36]. With the increasing use of IoT, the number of related tools is increased. The speed of data transfer, network security, and data control are among the concerns of this technology [37]. IoT can provide important information, such as temperature, speed, and other indicators at all stages of production, transmission and supply.

Transaction Records: The main root of the blockchain is the decentralized ledger, which allows any activity to be tracked. Each user has a copy of the ledger and access to transaction information. At the same time, the information of the goods is recorded and controlled in these transaction records. This feature is also used as a platform for cryptocurrencies and allows for financial exchange using digital currency [19].

Traceability Tag: The blockchain tracking tag system is different from the barcode and RFID system. Traceability tags can be installed without the need for hardware and equipment, and without additional process, it is possible to install the tag on other entities. Traceability tags are stored in data blocks and are associated with goods. When a product is sold, its ownership information changes in the traceability tag.

Smart Contracts: In a blockchain system, a smart contract is a programmable infrastructure. All users can set up a smart contract based on their needs. All files of smart contracts are stored in the information blocks with precise details, and when there is a dispute between the parties, clear information is approved by other network operators [38].

Kshetri [6] pointed to the impact of blockchain on supply chain and increased confidence and accountability and provided various mechanisms for implementing blockchain. Min [39] looked at the impact of blockchain technology on supply chain resilience. Perboli et al. [40] presented a standard methodology for implementing blockchain technology in the food industry and addressed critical factors in the implementation of this technology. In the study of Mistry et al. [41], IoT industrial automation model based on 5G technology and blockchain was presented using the systematic review method. Finally, the proposed plans were evaluated based on different end-user indicators [41]. In the study of Helo and Hao [25], a model for supply chain and blockchain-based operations is presented. Based on this, different supply chain software was studied and classified based on blockchain and finally logistics monitoring system was presented and implemented in Ethereum platform. Awwad et al. [42] addressed the combination of IoT and blockchain technology and its application in the supply chain, and mentioned advantages, such as cost reduction, transparency, flexibility and increased speed of service delivery. Francisco and Swanson [43] used technology acceptance models to examine the application of blockchain technology in product tracking in the supply chain. Frizzo-Barker et al. [26] systematically reviewed the applications of blockchain disruptive technology in businesses. In the study of Venkatesh et al. [44], blockchain-based architecture was presented, which was designed based on the social sustainability of the supply chain. In their study, social sustainability meant creating a suitable work environment, maintaining the health of employees, a fair payment system, and creating a free communication platform. The global supply chain has also become more complex in recent years because different individuals and companies around the world have found it easier to interact with each other. Social sustainability and the maintenance of appropriate workers and employees in the production chain are also possible based on the blockchain technology [44].

### 2.3. Blockchain technology in agricultural supply chain

Smart agriculture is the use of technologies, such as the Internet of Things, big data, artificial intelligence and cloud computing in traditional agriculture. Blockchain technology is also used in smart agriculture [45]. Technological advances have had a great impact on agricultural production. With the help of sensor devices and the Internet of Things (IoT), farmers can remotely access their farm information such as temperature, soil moisture and plant pests [46]. Traditional IoT-based tracking systems using Wireless Sensor Network (WSN) are an acceptable way to monitor and track agri-food chains [47]. But the centralization of the IoT-based system makes it difficult for other stakeholders, such as consumers and vendors, to track information, and network security is reduced due to lack of transparency. Feng et al. [48] have improved traceability and chain transparency by providing a hybrid IoT model based on blockchain. In this model, network information can be traced by consumers and other stakeholders in a decentralized manner from the time of product production by the farmer to the time of distribution and sale, and the use of hash encryption functions increases network security. Many logistics information systems in the Agri-food supply chain record information about orders and receipts, but do not pay attention to features, such as transparency, traceability, auditability [49]. Using blockchain technology in the Agri-food supply chain, all nodes' operations on the network are visible, and all information recorded is based on consensus among network members [19]. In centralized information systems, there is information asymmetry between stakeholders [50], and consumers do not have access to some product information [51], and different stakeholders in the supply chain may use different information systems, making it difficult to track the system [52]. Blockchain-based system uses a standard platform to create information transparency among different stakeholders and provide real-time information to stakeholders and consumers. The use of IoT-based tracking systems in the agricultural chain using a centralized platform leads to challenges, such as data integrity and tampering [53]. The use of the blockchain technology increases the validity of the data in the network and reduces the need for a third party to monitor the network and control the information [54]. Various studies have been conducted on the application of blockchain technology in the agricultural industry. In their study, Mirabelli and Solina [22] examined the trend of studies in the field of traceability tracking systems based on the blockchain in the Agri-Food supply chain and examined the future challenges in this field.

Bermeo-Almeida et al [55] systematically reviewed the applications of blockchain in agriculture. Their results showed that 60% of papers are focused on food supply chain. Also, 50% of the studies on blockchain in agriculture are dominated by Asian community researchers, especially from China and the half of the studies addressed challenges related to privacy and security of the Internet of Things with blockchain technology.

Caro et al. [53] proposed a solution based on blockchain technology for Agri-Food supply chain management, which increases control and trust in information gathered based on the Internet of Things in the supply chain. Tian [56] introduced a tracking system based on blockchain technology and RFID for the Agri-food supply chain. Also, Tian [21] built a food supply chain traceability system for real-time food tracing based on HACCP (Hazard Analysis and Critical Control Points), blockchain and Internet of things, which could provide an information platform for all the supply chain members with openness, transparency, neutrality, reliability and security. The results of the Stranieri et al. [57] study also showed that blockchain has a positive effect on the

**Table 1 – Literature review results on supply chain maturity models.**

| References | Dimensions | Maturity Stages |
| --- | --- | --- |
| [61] | 13 key attributes related to technologies and business and knowledge management | 4 stages |
| [62] | Only a diversification corporate strategy is being considered as the enabler for Industry 4.0 | 3 stages |
| [64] | Purchase & Supply, Production, Storage & distribution, Sales | 3 stages |
| [65] | 4 dimensions to be met by the manufacturing backbone | 5 stages |
| [66] | Real time, Big Data, robots, smart product, cloud-supported network, drones, 3D printing, IoT, e-shops | 5 stages |
| [60] | IoT, GPS, RFID, drones, 3D printing, applications, robots, 3D scanning, augmented reality, smart products, RTLS (real time locating systems), IT systems (ERP, WMS, cloud systems) | 5 stages |

profit or return on investment of the agri-food supply chain. It improves the quality of products by improving consumer access to information and the possibility of feedback, as well as by creating transparency and sharing information between stakeholders.

Considering the review of previous studies, it is observed that the study of new technologies, including blockchain, is important in supply chain management. The originality of the research is ranking the dimensions of the blockchain in the agriculture industry and presenting the maturity model of the blockchain.

### 2.4. *Supply chain maturity models*

Some blockchain maturity models, such as the one in Wang's study [58], have generally examined blockchain maturity, and no specific model has been proposed for the supply chain. Also, various maturity models are offered in the supply chain domain. Each model has different dimensions and number of levels. In recent years, most of the studies of maturity model have focused on industry 4.0 and Logistic 4.0 technologies. Supply chain technology studies are often comprehensive on industry 4.0 technologies. Table 1 presents some maturity models. Because until the time of this study, there was no study examining the maturity model of blockchain in the supply chain. On the other hand, blockchain technology is one of the technologies related to industry 4.0 [59], therefore, the classification of the maturity model of industry 4.0 has been used in the supply chain, which is more pervasive. The five-step model of Oleśków-Szłapka and Stachowiak [60] incorporates a number of technologies from Industry 4.0, which complements previous studies [61,62], and has been used in subsequent studies such as Facchini [63], and its validity is acceptable. On the other hand, the five-level classification of the Oleśków-Szłapka and Stachowiak model corresponds to the classification of the Wang model.

## 3. Materials and methods

This research is applied. Blockchain has different uses in the agricultural industry. Therefore, in the first phase, the dimensions of blockchain technology were ranked based on their application in the agricultural supply chain. The SWARA method was used to examine the opinion of experts to rank the five dimensions of the blockchain in accordance with Kshetri's study [6]. The SWARA method is presented by Keršuliene et al. [67] and enables the decision maker to select, weight, and evaluate indicators. The most important advantage of the SWARA method is the evaluation of experts' attention to weighing indicators and expert consultation [68]. The committee of research experts included 13 faculty members from the Schools of Agriculture and food sciences who had a background in smart agricultural research and new technologies. A virtual group was formed to form a panel of experts so that people could express their ideas and opinions.

In this part of designing the blockchain maturity model, there is a need to identify effective company dimensions in accepting and using technology. Given that this blockchain maturity model in the supply chain has not been studied in previous studies and blockchain technology is part of disrup-

**Table 2 – Dimensions and maturity items of blockchain Maturity Model.**

| Dimension | Exemplary maturity item |
| --- | --- |
| $D_1$-Strategy | Implementation blockchain roadmap, Adaption of business models |
| $D_2$-Governance | Suitability of technological standards, Protection of intellectual property |
| $D_3$-Leadership | Management competences and methods, Willingness of leaders |
| $D_4$-Culture | Value of ICT in company, Transparency, Knowledge sharing |
| $D_5$-People | ICT competences of employees, openness of employees to new technology |
| $D_6$-Customers | Digitalization of services, Utilization of customer data |
| $D_7$-Operations | Decentralization of processes |
| $D_8$-Products | Product integration into other systems, Individualization of products, Tracer |
| $D_9$-Technology | Sensors, Utilization of mobile devices |

**Table 3 – Reliability and Validity of the model.**

| Variables | Cronbach alpha | Reliability |
|---|---|---|
| Strategy | 0.833 | Established |
| Governance | 0.813 | Established |
| Leadership | 0.814 | Established |
| Culture | 0.846 | Established |
| People | 0.776 | Established |
| Customers | 0.823 | Established |
| Operations | 0.734 | Established |
| Products | 0.742 | Established |
| Technology | 0.821 | Established |

**Table 4 – Final results of SWARA method in weighting blockchain dimensions.**

| | Comparative importance of average value $S_j$ | Coefficient $k_j = s_j + 1$ | Recalculated weight $w_j = \frac{x_{j-1}}{k_j}$ | Weight $q_j = \frac{w_j}{\sum w_j}$ |
|---|---|---|---|---|
| Smart contracts | | 1 | 1 | 0.263 |
| Internet of things | 0.163 | 1.163 | 0.859 | 0.225 |
| Transaction records | 0.146 | 1.146 | 0.750 | 0.197 |
| Traceability Tag | 0.159 | 1.159 | 0.647 | 0.170 |
| Digital documents | 0.172 | 1.172 | 0.552 | 0.145 |

tive technologies in industry 4.0, the dimensions of industry 4.0 maturity models have been used as a complete model here. Based on this, the Schumacher et al. [69] model was selected because 62 maturity items are classified as nine company dimensions, which indicates the comprehensiveness of the classification of dimensions. Convergent validity related to the nine dimensions is also examined in the next step. Nine company dimensions for blockchain technology are shown in Table 2.

In the last step, the proposed model was tested in a food manufacturing company in Iran. In Iran as a developing country located at the heart of the Middle East, agriculture has a very significant role in the economy of the country. The released data by FAO, 17% of the population of Iran in 2017 was working in the agriculture sector and more than 28% of the lands of the country were dedicated to agriculture. Moreover, 9.5% of Iran's GDP was for the agriculture sector [70]. Also, Iran is currently under tremendous sanctions and therefore importation of some agricultural crops is not possible [67]. Hence, usage of modern technology and techniques in agriculture for acquiring quality crops in the country is a necessity. The company in question had 470 employees and was in contact with 13 companies in the supply chain. According to Sanae et al. [64], there are four sections for supply chain. Therefore, the statistical samples were selected from managers and experts of four groups of supply and purchase, production, storage and distribution, and sales, turning out to be 130 people. During several sessions with the presence of the researcher, different applications of blockchain were described for members of the study community. Then, information related to each application of the blockchain in the supply chain of the agriculture industry was collected in 45 days using the questionnaire. The designed questionnaire was edited according to the opinion of experts. Thus, it can be claimed that the questionnaire had an acceptable face validity. To evaluate the reliability of research instruments Cronbach's alpha coefficients were used. Reliability is acceptable when Cronbach's alpha equal to 0.7 or are over that [71]. The scales show good reliability with Cronbach's alphas > 0.7 shown in Table 3.

## 4. Results and discussion

The five uses of blockchain were ranked based on expert opinions to identify the importance of each in the agricultural supply chain. The results of the ranking coefficients using the SWARA method are shown in Table 4. Based on the results of Table 4, it is clear that smart contracts, IoT, and transaction

**Table 5 – Blockchain maturity levels.**

| Level | Characteristics | Degree of maturity |
|---|---|---|
| Ignoring | do not know about blockchain applications improving information flows | $0 \leq M < 20$ |
| Defining | know about blockchain applications improving information flows but do not use it | $20 \leq M < 40$ |
| Adopting | some blockchain applications improving information flows are implemented | $40 \leq M < 60$ |
| Managing | many blockchain applications improving information flows are implemented | $60 \leq M < 80$ |
| Integrated | all possible blockchain applications improving information flows are implemented | $80 \leq M \leq 100$ |

**Table 6 – The rate of blockchain application in each dimension.**

| | $D_1$ | $D_2$ | $D_3$ | $D_4$ | $D_5$ | $D_6$ | $D_7$ | $D_8$ | $D_9$ | $B_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Smart contracts | 1.17 | 1.14 | 1.23 | 1.19 | 1.18 | 1.2 | 1.06 | 1.31 | 1.45 | 24.2 |
| Internet of things | 1.13 | 1.25 | 1.11 | 1.42 | 1.28 | 1.19 | 1 | 1.06 | 1 | 23.2 |
| Transaction records | 2.11 | 1.75 | 2.78 | 3.23 | 3.16 | 2.27 | 1.94 | 2.31 | 2.05 | 48.1 |
| Traceability Tag | 2.21 | 1.25 | 1.43 | 1.09 | 1.11 | 1.19 | 1.17 | 2.11 | 3.11 | 32.6 |
| Digital documents | 3.77 | 3.89 | 3.76 | 2.93 | 3.45 | 3.79 | 2.98 | 4.09 | 4.27 | 73.1 |

records are the most important among the applications of blockchain in the agricultural industry.

To design a blockchain maturity assessment model based on Formula (1), the degree of adoption of each blockchain dimension is calculated. This formula is calculated based on the sum of the values of each dimension.

$$B_i = \frac{\sum_{n=1}^{9} d_n}{\text{Maximum point possible}} \times 100\% \tag{1}$$

Here:

$B_i$ = degree of adoption of blockchain application i
$d_n$ = score of dimension n

According to Formula (2), the maturity of blockchain technology is calculated based on the adoption of each dimension and taking into account the weight of each.

$$M = \sum_{i=1}^{5} \omega_i B_i \tag{2}$$

M = degree of maturity of blockchain
$\omega_i$ = weight of blockchain application i

As mentioned, there are different maturity models for the supply chain. Here, the maturity model of Oleśków-Szłapka and Stachowiak [60] has been used to determine the maturity levels of the blockchain. The maturity level of blockchain technology is shown in Table 5.

### 4.1. *Case study*

According to the questionnaire distributed among managers and experts in the four areas of supply chain, the degree of adoption of each blockchain dimension in the supply chain under study was obtained based on Formula (1). For example, the adoption rate of transaction records is shown below. Given that the questionnaire questions were designed based on a 5-point Likert scale, a maximum score of 45 was considered.

$$B_3 = \frac{2.114 + 1.756 + 2.785 + 3.234 + 3.163 + 2.278 + 1.945 + 2.318 + 2.056}{45} \times 100\%$$

$$B_3 = \frac{21.649}{45} \times 100\% = 48.1\%$$

Table 6 shows the rate of blockchain technology application in each dimension. The last column of the table shows the degree of adoption according to Formula (1).

Formula (2) has been used to calculate the overall maturity of blockchain technology, and the obtained coefficients have been considered in the calculation according to the experts' opinion.

$$M = (0.263 \times 0.24) + (0.225 \times 0.23) + (0.197 \times 0.48) + (0.170 \times 0.32) + (0.145 \times 0.73) = 0.369\,6$$

According to the results of the model calculation, the maturity of blockchain technology in the study sample is 36.96%. According to Table 5, the maturity of the blockchain of the study sample is at the Defining level. That is, there is information and knowledge about the applications of blockchain technology, but its application has not yet been done in an acceptable way and the platform for its use has not been provided in the study sample. Fig. 1 shows the adoption rate of each blockchain dimension in the company under study. Digital documents are in the best state, meaning that there is office automation in the supply chain, but it's not practical to use smart contracts as well as the IoT and digital currencies. Due to the fact that Iran is under sanctions by the United States and some European countries [72], the entry of many technological equipment is facing problems, so the correctness of the result regarding the poor implementation of technology is confirmed.

This paper sought to provide a model for assessing the maturity of blockchain technology in the agricultural and food supply chain. Based on the Kshetri model [6], five dimensions of blockchain technology were identified. In response to the first question of the research, the dimensions of the blockchain were ranked according to the opinion of agriculture industry experts and using the SWARA method. The findings of the first part of the study showed that smart contracts and the IoT are the most important applications of blockchain technology in the agriculture industry. Due to the relationship between farmers and food production and distribution companies in the supply chain of the agriculture industry, the use of blockchain technology as a platform for smart contracts is important to clarify information and resolve disputes between different stakeholders. Also, IoT allows for tracking goods and food shipments and people. If the IoT information is placed in the distributed platform of the blockchain, the reliability and security of the information will increase, so the IoT data is one of the most important applications of the blockchain. In this regard, Khanna and Kaur [73] compre-

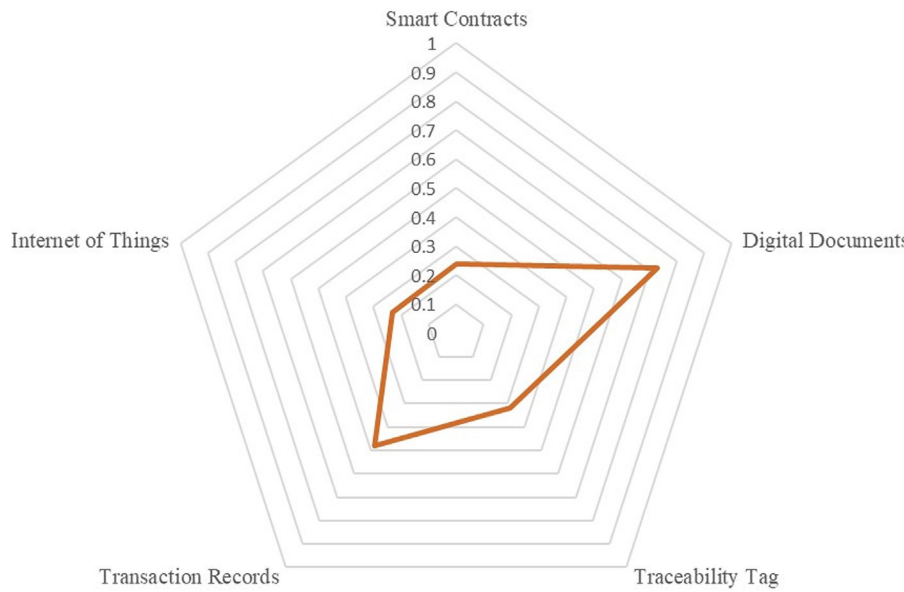


**Fig. 1 – The maturity degree of an Iranian company.**

hensively reviewed the applications of the IoT in precision agriculture. Verdouw et al. [18] provided an IoT-based architectural framework for food and agricultural systems. The validity and reliability of their proposed framework were confirmed in multiple case studies in Europe. Based on the findings, transaction records and traceability tag, and finally digital documents were the next priorities for blockchain technology applications. The use of data distributed in the blockchain network enables transparency of decisions along the supply chain. Thus, farmers and contractors in this area, and even government agencies, have access to reliable information, allowing better planning and better market control. In the following, we can mention the capability of using cryptocurrencies in the financial transactions of the supply chain. Due to the context of these exchanges through the decentralized system, blockchain causes high-security financial payments and non-dependence on the government and traditional payment systems. Ghosh et al. [74] pointed to the widespread use of digital currencies in e-commerce and considered security issues to be one of the most important challenges in this area. Traceability tag makes it possible to control the products of farms and foodstuffs, which improves the quality of service in the supply chain of the food industry and agriculture. Finally, the latest application of blockchain technology, such as the use of digital documents, information systems, and automation of work processes throughout the supply chain, can lead to improved information flow, more accurate control, and resource management. Janssen et al. [75] noted the importance of using information and communication technology in agriculture and the role of the new generation of information systems and decision support systems in the development of agricultural activities. Also, adoption of appropriate smart technologies and then their customization with the need of the technology users could tremendously benefit not only in optimal usage of resources but also in driving agriculture toward more productivity and profitability [76].

In response to the second research question, a model was designed to evaluate the maturity of blockchain technology based on its dimensions and their coefficients of importance. The model was then tested in the supply chain of an Iranian company. Comparing the model of this study with the models presented in the studies of Pacchini et al. [77] and Lucato et al. [78], it can be said that the model presented in the present research is specialized in terms of blockchain technology applications, in which the blockchain dimensions were weighed in the agriculture sector. It also used the nine dimensions of maturity that were more comprehensive. The test results of the proposed model in the study sample showed that the maturity of the blockchain is at the Defining level. This means that the supply chain under study has the theoretical knowledge of blockchain technology, but the platform for its implementation and use has not been fully possible. Also, in the study sample, digital documents had the best status among the various applications of blockchain. This means that the company has been successful in implementing information systems and automating work processes. However, it is not in a good status in the implementation of smart contracts as well as the IoT. Ronaghi et al. [79] noted the agricultural sector is one of the most important sectors in the economies of developing countries but due to various sanctions against Iran [72], it is difficult to import some equipment related to tracking goods and the IoT. Also, the Iranian government has not recognized digital currencies and they have not entered the economic cycle. Therefore, such a finding is justifiable.

One of the limitations of this research was the use of the crisp approach in calculating and ranking dimensions. Therefore, future research is recommended to use fuzzy approaches and grey theory. Also, the proposed research model has been tested in Iran, so it is recommended to test the model in developed countries and compare the results with the output of this research. Finally, in this study, a maturity model was used for the entire supply chain. Future studies are suggested to apply different maturity models for each part of the supply chain.

## 5. Conclusion

The use of blockchain technology in the Agri-food supply chain allows stakeholders and consumers access reliable information. Blockchain technology also increases the ability to track goods and reduces the need for a third party to monitor the network and control information. Among the various applications of blockchain, smart contract (0.263), IoT (0.225), transaction records (0.197), traceability tag (0.170), and digital documents (0.145) were the most important elements in the agricultural supply chain in order of priority. Therefore, the use of blockchain technology plays an important role in clarifying contracts between farmers, landowners, manufacturing companies, vendors and government agencies. The use of IoT technology under blockchain technology also provides reliable data on product tracking. The use of digital currencies in the blockchain platform is also a good way to finance the supply chain. The proposed model of this research is a suitable tool for evaluating the maturity level of blockchain, by which an organization can evaluate its progress in using this technology and using its capabilities. Using the blockchain maturity model, individuals and organizations involved in the Agri-food supply chain, such as farmers, gardeners, producers, distributors and sellers of food products, can assess their readiness to adopt and implement blockchain technology. Using the results of the maturity level determination model, managers in each department can plan for the development of blockchain technology adoption so that they can achieve a higher level. According to the maturity results of the study sample in Iran, in addition to the fact that the company's managers must provide the necessary platform for creating a blockchain software platform and using smart contracts, they must purchase and install the necessary equipment to track agricultural goods and products. Also, the Ministry of Agriculture and the Ministry of Information and Communication Technology of Iran should provide the necessary facilities for hardware and telecommunication bandwidth equipment to support companies active in the field of food and agriculture.

## Funding

Not applicable.

## Availability of data and material

All data generated or analyzed during this study are included in this article.

## Declaration of Competing Interest

The author declares no conflict of interest.

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