Food supply chain in the era of Industry 4.0: Blockchain technology implementation opportunities and impediments from the perspective of people, process, performance, and technology

Abstract

The prevention of food loss throughout the supply chain, including manufacturers, has become a major challenge for a number of organizations. In addition, consumers are also increasingly interested in the authenticity of food and want to ensure that they receive the right quality of food. To address this issue, there is a need for reliable and robust tools to be available in the Industry 4.0 era that can trace the food throughout the supply chain from the farm through processing until it reaches the customer and, thus, ensure transparency. Using the people, process, and technology (PPT) model, this paper develops a blockchain-enabled food supply chain framework including the future opportunities and the present impediments based on the systematic literature review and semi-structured case interviews from the context of emerging economies. The study investigates the suitability of blockchain technology in resolving major challenges, such as traceability, trust, and accountability in the food industry. The study further paves the way for future researchers to address the technological and people-related challenges in the Industry 4.0 era to mitigate the emerging problems in the food sector. Interestingly, we did not find many issues in process- and performance-related aspects. The study offers empirical evidence of blockchain technology implementation in the Industry 4.0 era that opens up the discussion for future researchers and lists the potential threats.

Keywords: Blockchain, Industry 4.0; Food manufacturers, Food supply chain, Food security, Track and Tracing

1. Introduction

Food loss is often described as a "farm-to-fork" damage problem (Aung & Chang, 2014); it is defined as any food substance, liquid or solid, cooked or uncooked, that is thrown away or discarded including food processors. Food loss is a global challenge in the developing and the developed countries (de Lange & Nahman, 2015). The United Nations Food and Agriculture Organization (FAO) estimates that around 40 percent of the food produced is lost or wasted throughout the entire food chain (Warker, 2018). This percentage is even higher in developing countries. Food travels through what is often a vast network of farmers, retailers, distributors, transporters, storage facilities, processors, and suppliers before reaching the end consumer and has to undergo processes such as post-production, harvesting, processing (warehouses, packaging), transportation, distribution, and sales. Yet in almost every case, this journey remains an unseen dimension of purchased food products (Ahlmann, 2018). In a food supply chain, loss can be classified into five categories: agricultural loss, postharvest loss, processing loss, distribution loss, and consumption loss (Kummu et al., 2012). Most food loss occurs throughout the food system starting at farms and ending at households during post-harvest including processing (warehouses, packaging), transportation and distribution, availability in the supermarkets, and purchase by the consumers. Food loss in developing countries is much more prevalent in the early and the middle stages of the supply chain, and it is primarily related to the inadequate supply chain and logistics infrastructure and management, low levels of technology use, and low investment in the food production systems. In contrast, in developed countries, a significant amount of food is wasted during the marketing and consumption stages (Warker, 2018).

The increasing globalization of food production and trade has opened up the access to food and led to an increase in consumer options (Fox et al., 2018). This not only makes the supply chain longer and more complex, but it also adds significant tracking and safety challenges, which necessitates change to the farm-to-fork business models (King et al., 2017). In addition, the intrusion of counterfeit products is affecting both the integrity of brands and the wellbeing of consumers (Chang et al., 2019). The food supply chain is facing uncertainties because of product perishability. In addition, "information asymmetry" between the stakeholders is one of the major factors that lead to food fraud (Mao et al., 2018; Galvez et al., 2018). Thus, there is a need for information sharing due to pilferage, inefficient transactions, etc. that lead to a lack of trust among the supply chain partners. In the agri-food sector, traceability of food is becoming a major differentiator and so is imperative for organizations (Saberi et al., 2019). Thus, it is important to have a centralized and effective traceability system that ensures information connectivity among all the partners (Galvez et al., 2018; Fatorachian & Kazemi, 2018).

The food tracking system enables the supply chain to measure the level of safety of perishable food products, tracing the journey from where they are grown, handled, or stored and under what conditions they are transported or processed, thus leading to the development of a transparent and authentic chain of records of the food ecosystem (Godsiff, 2016). In the food industry, the provenance and traceability of information helps to improve the quality as well as the safety of food (Saberi et al., 2019). In addition, the evolution of technologies in the era of Industry 4.0 has the potential to prevent unnecessary waste and reduce the economic burden of product recalls, outbreaks, cross contamination, etc. Advanced technologies, including the Internet of Things (IoT) and blockchain, have been considered in many industries to increase traceability, but in the food industry, little progress has been made, particularly as regards creating more secure food-supply chains. However, other than the above reported issues, many unknown impediments related to people, process, technology, and performance can creep into the food supply chain and so need further investigation.

While blockchain technology is relatively a new technology, interest in using the technology in companies and the development of use cases is growing exponentially (Bumblauskas et al., 2020). In this process, blockchain technology can provide a way to achieve the immutable storage of data that can reduce the need for third party verifications (Lin & Liao, 2017). Non-involvement of third party engagement will be helpful for businesses and consumers in the contemporary complex supply chains in the era of Industry 4.0 (Perboli et al., 2018). In particular, this technology has a greater viability in the food industry, as it can help to reduce the food loss along global supply chain stages, monitor temperature variation during the transport, increase transparency of food processes, and so on. Besides traceability, the implementation of blockchain technology can help to reduce labor costs (Kshetri, 2018) and other operational costs when lean and automated processes are in practice (Dobrovnik et al., 2018).

To date, there has been very little research on blockchain technology, and thus, it is difficult for organizations to understand how the blockchain technology can be implemented in Industry 4.0 (Galvez et al., 2018). The literature and empirical evidence of blockchain implementation issues in supply chain management is extremely scarce (Queiroz et al., 2019; Calatayud et al., 2019; Chang et al., 2019). However, as blockchain technology offers significant advantages in the era of Industry 4.0, there is a need for research on how its implementation can help businesses create value (Treiblmaier, 2018; Dobrovnik et al., 2018; Bumblauskas et al., 2020). There are several ongoing pilot studies globally, so it is not obvious what are the typical issues that prevent the implementation of this technology and to what extent it is adaptable to the context of emerging economies typically in the context of the food supply chain. Hence, from the research perspective, this paper explores the opportunities for and impediments to using blockchain technology in a food supply chain.

Briefly, this study investigates some of the following pragmatic open questions:

1. What are the opportunities for and impediments to implementing blockchain technology in the era of Industry 4.0 food supply chains?
2. What are the specific implementation issues in terms of people, processes, technology, and performance perspectives?

In particular, we have used the people, process, and technology (PPT) model to address the objectives of this research study (Prodan et al., 2015). PPT is considered the viable model for transforming and managing an organization. In accordance with this framework, people-related strategies and processes evolve with the emergence of technology. The proper balance of PPT along with performance will enable firms to be successful. The PPT model has been applied in a number of disciplines although it is widely popular in the information technology management discipline amongst others. Hence, the PPT model is a viable framework for understanding the research challenges in blockchain implementation in supply chains.

Primarily, the major contribution of this study is to develop a blockchain-enabled food supply chain framework that classifies the opportunities and impediments in accordance with process, people, technology, and performance categories. We used the combination of systematic literature review (SLR) and semi-structured interviews to achieve the above stated objectives. The SLR helped us to know about the opportunities for and impediments to the use of blockchains in the food supply chain from an overall perspective, while semi-structured interviews helped us to know the perspective of professionals specifically from the Turkish and Indian food supply chains stakeholders.

The rest of the paper is organized as follows. Section 2 reviews the literature on food supply chain challenges, blockchain technology, and the potential use of blockchain technology in the food supply chain. Section 3 presents the research methodology adopted to achieve the desired objectives of this study. The results are presented in Section 4, and finally, conclusions and limitations are discussed in Section 5.

2. Literature review

2.1 Food supply chain challenges

Food quality and safety is becoming increasingly important, and failure to implement rigorous monitoring and traceability processes can lead to illness and severe reputational damage to an organization (Aung & Chang, 2014). Recently, several food chains have been subjected to safety scandals, such as the horsemeat scandal, the peanut butter salmonella outbreak, etc. (Crossey, 2017). If consumers cannot be certain that the food they are eating is safe and has been authentically sourced, they are likely to shop elsewhere, which can have a profound impact on a business's bottom line.

Maintaining food safety and providing the customer with the right quality food is a significant challenge. The major difference between a food supply chain and the other supply chains is the change in quality of the food material between the point of origin and the point of consumption (Apaiah et al., 2005). Thus, food products need to be traced throughout the supply chain to ensure that issues regarding the right quality, origin information, and transparency- and tracing-related issues are managed.

Indeed, the major issues that need to be managed to ensure traceability in a food supply chain can be sub-categorized as technical, managerial, and environmental (Aung & Chang, 2014). The greatest challenge with the traceability of food is the exchange of information in a standardized format, precisely and effectively, to all the stakeholders involved in the supply chain (Moe, 1998; Aung & Chang, 2014). Paper-based systems are widely used in many small and large organizations to promote traceability, since digital systems are expensive, and operating and maintaining them requires extensive investment in resources (Karippacheril et al., 2017). However, paper-based systems have a number of limitations. Another barrier to food traceability is the associated costs in implementing traceability systems, especially for small scale producers specifically in developing economies (Kelepouris et al., 2007; Aung & Chang, 2014). The high administrative costs also add significantly to the cost of technology. Finally, standardization is difficult because of the different features of the members involved in the supply chain (Wognum et al., 2011). Thus, there is a need for cost effective systems that can provide accurate, up-to-date, and reliable information in a standardized format to all the stakeholders involved in the food supply chain (Opara, 2003).

2.2 Industry 4.0 and technological adoption in food supply chain

The recent review by Ben-Daya et al. (2019) indicated the availability of conceptual models for IoT applications in the food and manufacturing industries and the scarcity of analytical and empirical studies. The food traceability systems require the identification of entities and locations to follow the journey of food in the supply chain in the era of Industry 4.0. Data-capture technologies include radio frequency identification (RFID), barcodes, wireless sensor network (WSN), alphanumeric codes, etc. RFID has been found to be the most advanced technology for food traceability (Aung & Chang, 2014), and has been applied by a number of organizations. Regattieri et al. (2007) proposed a system that uses the combination of alphanumeric code and RFID to trace cheese products and that also allows the customers to trace the product they have purchased. Similarly, Shanahan et al. (2009) presented a framework to trace beef from farm to slaughter, based on RFID technology. For internal traceability and chain traceability of a grain supply chain, Thakur and Hurburgh (2010) recommended a generalized framework that uses a relational database management system and XML. In addition, Ruiz-Garcia et al. (2010) suggested a model that uses web-based systems for tracking batch products throughout the food supply chain. However, RFID systems have certain disadvantages; for example, the cost of the tags used in RFID systems is high (Aarnisalo et al., 2007). Moreover, it is difficult to achieve 100% readability of

RFID tags through metal, glass, and liquid (Petersen, 2004). Thus, there is a need for systems that are cost-effective, are compatible with the existing technology, can serve the required purpose, and most importantly, can be adopted by all organizations.

2.3 Blockchain review

A blockchain is a reliable and unalterable digital data ledger for monitoring the transactions through the distributed consensus process (Kamble et al., 2019; Galvez et al., 2018). As a new business collaboration tool, blockchain technology supports a secure, shared data network and allows untrusted parties to reach a consensus on a shared digital history, without using a trusted intermediary (Swan, 2015; Calatayud et al., 2019). A blockchain does not need any centralized authority and eliminates intermediaries in the process, allowing for faster, safer, and more efficient communication and operations between two parties (Pilkington, 2016). Furthermore, smart contracts, also known as programmable protocols, are used in a blockchain to enable parties to agree on certain conditions. This also allows the sensitive data on the blockchain to be stored in the database encrypted with hash algorithms, so that the data can be protected securely (Ahlmann, 2018). A blockchain enables the visibility of contracts across members in the supply network including agreements and regulatory check-points (Marques et al. 2019). As mentioned earlier, a blockchain's inherent immutable characteristic supports the authenticity of information (Dolgui et al., 2019). Blockchain technology is at the early stage of development (Kshetri, 2017; Calatayud et al., 2019); however, it has made substantial progress in the last five years. Everledger is using blockchain technology to transfer their diamonds in a trusted and credible way. For example, if we see a tag such as "Everledger satisfied", then our mobile phone is able to scan the IoT chip for the diamond's history and transactions.

The blockchain technology was first conceptualized in 2008 in the financial sector, where it was known as a peer-to-peer electronic cash system (Nakamoto, 2008). Initially, it was used as the foundation of a fully distributed crypto-currency unit (bitcoin), but it has gradually expanded into other sectors, such as the healthcare, insurance, and agriculture industries and e-commerce to improve full transparency and accountability (Subramanian et al., 2020). Blockchain technology is primarily recognized for secured crypto money transactions (Crosby et al., 2016), and potentially, its applications in other sectors can deal with asset ownership, acceleration of transaction time, cost reduction, and reduced risk of fraud. Blockchain technology is also being integrated by a number of manufacturing companies (Xu et al., 2018). Thus, blockchain technology has the potential to be applied in multiple industries and to initiate organizational change (Viswanadham, 2018).

Blockchain technology stores and shares information across a network of users in an open virtual space, and it allows users to view all the transactions simultaneously and in real-time (Wang et al., 2019). Each block contains the data of all the transactions in the system within a period of time, and it creates a digital footprint which can be used to verify the validity of the information and connect with the next block (Beck et al., 2016). There can be a huge number of such blocks in the blockchain, and the blocks are linked to each other (like a chain) in a proper linear, chronological order with every block containing a hash of the previous block. The changes to the information that is stored in the ledger needs approval by consensus from each node of the network (Calatayud et al., 2019). This is possible because in a blockchain, the data infrastructure is visible to all the entities, and no single entity controls the data (Niranjanamurthy et al., 2018; Wang et al., 2019). Thus, a blockchain provides better visibility in procurement, accurate and reliable data for analytics, and increased trust among all participants in a supply chain network. Blockchain technology also helps to reduce the human interaction in non-value-added activities (Bibby & Dehe, 2018). A selection of smart contracts can be included in the blockchain platform to facilitate secure communication between the users and machines (Ndraha et al., 2018).

Blockchain technology integrated with other artificial intelligence (AI) technologies can potentially mitigate issues surrounding trust, traceability, and collaboration in a supply chain. The cryptocurrency technology is also used by different applications, such as VeChain, for certification Waltonchain for apparel supply chains, Ambrosus for food and medicine supply chains, and Modum exclusively for pharma supply chains. VeChain has one of the most impressive partnership lists in the crypto industry. The network has partnered with DNV GL for certification, PWC for audit and advisory, Kuehne and Nagel for supply chain and logistics, the Chinese tobacco industry, and BitOcean & Fanghuwang for financial services. VeChain was launched in FY16 with functional smart contracts.

2.4 Blockchains in the food supply chain

Several of the issues discussed in the previous sections relate to improving collaboration and visibility in inventory and logistics to react promptly to disruptive events (Chang et al., 2019). Blockchain technology can help to improve the management and transparency of food supply chains (Tse et al., 2017; Ahlmann, 2018) by helping to trace the inventory of products throughout the supply chain (Pournader et al., 2019). However, monitoring the food supply chain and controlling food loss with blockchain technology is challenging. Indeed, the Global Food Traceability Centre has identified several challenges to the implementation of food traceability systems. These include a rapid shift in the preferences of customers, demands from regulators that are conflicting and overlapping, the variation of traceability by product and by industry, the lack of records, and weak technical systems that prevent rapid response times (Galvez et al., 2018).

There are currently only a few blockchain-based pilot applications in the food industry. The first pilot application to trace food using a blockchain was carried out by a startup called Provenance (Tripoli & Schmidhuber, 2018; Saberi et al. 2019). Yellowfin and skipjack tuna fish were tracked throughout the entire supply chain, from fishermen to distributors and retailers, and from shore to plate. The digital record was held on the blockchain, accessible to anyone with the unique identifier attached to the item such as a QR code or RFID tag or using any other hardware technology, so that the end users could track the whole journey of their tuna fish sandwiches on a smartphone and get information about producers, suppliers, and all the relevant procedures. In another pilot study, 10 major food suppliers including Walmart, Nestle, and Unilever, in collaboration with IBM built a consortium to apply blockchain technology to the food supply chain to improve food safety and transparency and to detect sources of contamination quickly (Barnard, 2017). Tian (2017) proposed a food traceability system based on the blockchain technology and IoT, which will deliver real time safety status of food products to supply chain partners. The proposed method provides the benefits of tracking and identifying fake products.

Maersk and IBM have started a venture to establish a global blockchain-based system for digitizing the trade workflows and end-to-end shipment tracking (Allison, 2017; DHL, 2018). Their blockchain concept has been tested using shipments of flowers to Royal Flora Holland from Kenya, and mandarin oranges from California and pineapples from Colombia into the Port of

Rotterdam. Another “food chain” prototype was developed by Deloitte (2017), which is capable of tracking all the ingredients in a particular product along the length of the supply chain. Such technology could potentially allow a consumer in China to pick up a product, scan an RFID tag on a mobile app, and be able to see where each ingredient in that product came from. In addition, Carrefour launched a food blockchain solution in early 2018 to track its quality line products. It was tested with the network of livestock farmers for chicken products from the hatchery for incubation to farm, slaughter, and processing and distribution, where a form of a simple QR code on the chicken's packaging is used. Subsequently, the solution was deployed for four other products: tomatoes, eggs, milk and Rocamadour cheese (Carrefour, 2018). Furthermore, Albert Heijn, Holland’s largest supermarket chain, has revealed a new blockchain system in partnership with its supplier, Refresco, to make the production chain of orange juice transparent. Thus, the customers can collect the maximum amount of information about the source of Albert Heijn’s own-brand “sustainable” product. The end-to-end route of its production, from Brazil to the Netherlands, can be traced through scanning a QR code on the orange juice carton (Huillet, 2018). The benefits of blockchain technology include the ability to monitor the operation’s progress in real time, provide data verification, reduce the risk of fraud, and shorten the cash cycle. Apart from transparency and traceability, blockchain technology also brings economic benefits in terms of facilitating faster transactions to pay farmers more quickly. It also prevents price coercion and retroactive payments in the food industry. Louis Dreyfus Company sold 60,000 tons of American soybeans to the Chinese governments by using blockchain-driven agriculture commodity trade, which demonstrated significant efficiency improvements for all participants in the chain. The entire transaction took only a week by reducing the total logistics time by 80% (LDC, 2018).

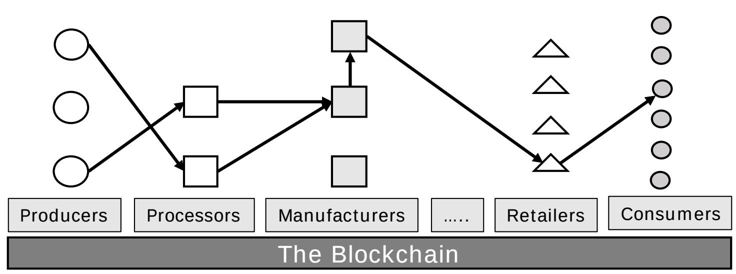

Figure 1: Blockchain in the Dairy Sector

A blockchain can be used in the food sector so that each and every party along the length of the supply chain (producers, processors, and distributors) can provide traceability information about their particular role and for each batch of the product (dates, places, farm buildings, distribution channels, potential treatments etc.). For the goods to be traceable from farm to fork, all the parties of the food supply chain that handle the goods should be linked to the blockchain and collaborate on a blockchain consortium to share all the food-related data, such as Hazard Analysis and Critical Control Point (HACCP) records, quality records, temperature records, humidity records, verification records, tracked food information, and so on. Each step is recorded in the blockchain to reduce the potential hazards in terms of spoilage (temperature, humidity, expiry), contamination (toxins, insect, bacteria, viruses) and compromise (tampering, misrepresentation, substitution). Figure 1 shows the blockchain in the dairy sector, where large commercial dairy companies face the challenge of tracking the provenance of their milk, as they often source from multiple milk producers (Deloitte, 2017). Further, the IoT could potentially play a role here. Internet-connected equipment, such as trucks and storage coolers, could monitor which objects they are housing and tag those objects with the relevant environmental conditions, such as temperature, humidity, light, shock, or location, and thus provide assurance that a product is safely handled through the entirety of its journey. Blockchain technology can help to inform the customer of the way it reached to them, especially for costly and sensitive items. For example, a medicine package might include a microchip sensor (IoT chip) that records every environment from the departure from manufacturing unit until it reaches at consumer’s hand. Moreover, the data have to be regularly updated on a shared and censorship-resistant blockchain ledger. This could be verified using a phone if the medicine were not available in the required environment. With the merger of IoT with a smarter ledger, i.e., the blockchain can verify the sensitive product rather than trusting the seller.

The stakeholders involved in the food supply chain from farm to fork are shown in Figure 2, which includes farmers; distributors; packers; processors; wholesalers; retailers; and customers, such as grocers, restaurants, traders, and end users, who jointly act and share food-related data using a blockchain consortium. the blockchain is the core of the solution, but on its own, it is not enough; it should be used with IoT devices, Auto-ID (RFID/NFC technology), GPS, GPRS, 5G, wireless sensor networks, and other digital applications. The joint responsibility and transparency benefits food security with low transaction costs and instantaneous application. The blockchain assigns unique digital identifiers (event-specific data) to food products including growth conditions, product ID, lot/batch/serial numbers, and expiration dates. Tracing a food journey can help prevent food waste and instigate end consumers to calculate the ecological footprint of the food they consume as well as rerouting the surplus food to regions that need it. In addition, the blockchain's shared register of food would enable supply chain members to identify the source of foodborne illnesses and reduce food fraud. A combination of blockchain and IoT sensors data would automate decisions made by supply-chain members including farmers, processors, distributors, and retailers through smart contracts to address food safety issues, identify and implement solutions for recurring problems, and proactively identify and remove products in the case of foodborne illnesses or recalls that are at an elevated risk of contamination based on the handling history. This means that manufacturers and retailers have the potential to eliminate products at risk before they even reach the consumer, thus reducing the issues that come from issuing a recall including cost, consumer safety, damaged brand reputations, and decreased customer loyalty.

As digital technologies are increasingly used to manage farms, blockchain technology will promote the sharing of on-farm data. In short, blockchain-based food tracking can ensure the following (ChainLink, 2018):

- provenance: stronger assurance of origin and chain-of-custody
- recalls: faster and more precise recalls
- freshness: fresher produce and meat, reduce waste and spoilage
- safety: fewer contamination incidents

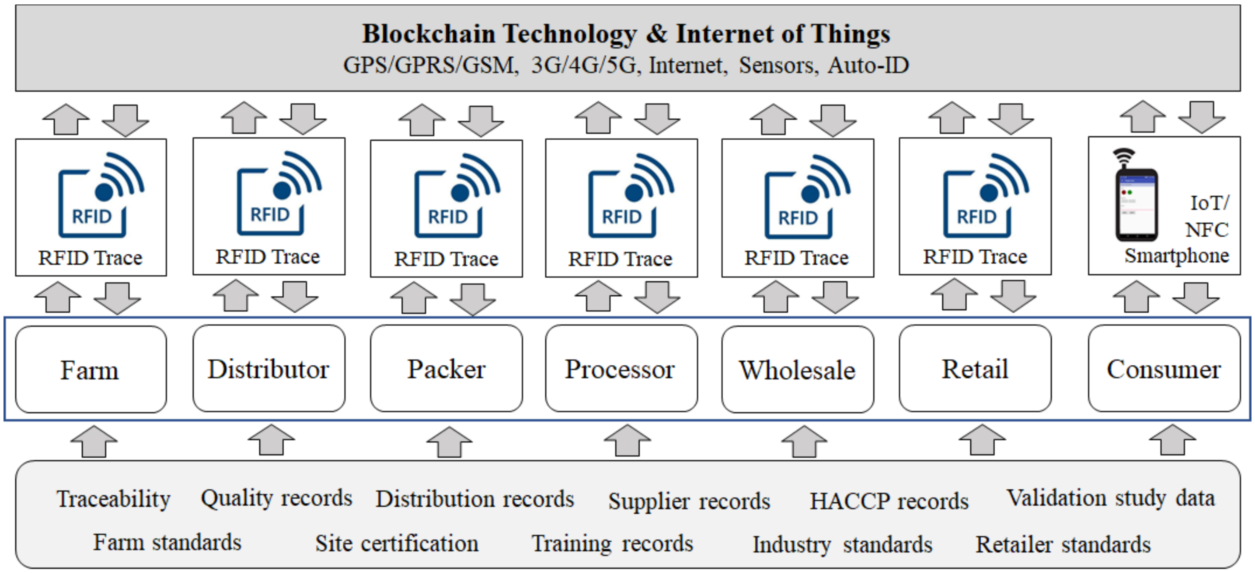

Figure 2: Blockchain-driven cold food supply chain

The development of blockchain applications also empowers the entire chain to be more responsive to any food-safety disasters, such as the horsemeat scandal and peanut butter salmonella outbreak in the agri-food industry, as mentioned earlier, and it prevents food fraud (Crossey, 2017). Blockchain technology thus offers immense potential for food safety and verification in the agri-food industry. In the food supply chain, for example, a retailer would know with whom his/her supplier had been dealing. Additionally, since transactions are not stored in any single location, it is almost impossible to hack the information. For consumers, by reading a simple QR code with an NFC-integrated smartphone (Crossey, 2017), data such as an animal's birth, use of antibiotics, vaccinations, and location where the livestock was harvested, can easily be conveyed to the consumers.

Conceptual and pilot studies have illustrated that there is a huge potential to scale up the technology to the food sector; however, at implementation level, it is very difficult to identify what are the drivers and barriers in integrating the use of blockchain technology in the food sector from the managerial perspectives, such as people, process, performance, and technology.

3. Methodology

The methodology of this research is based on a systematic literature review (SLR) and case interviews with the focused group of experts/stakeholders from the food industry.

3.1 Systematic literature review

A research strategy for SLR was adopted as per the three stages, such as "planning the review", "conducting the review" and "reporting and dissemination", offered in Tranfield et al. (2003) in order to review the most relevant literature. The three SLR stages are reported in the following sections.

(i) Planning the review:

Research scope: In this stage, the need for the review was identified to understand which studies have been published in the field of "food and blockchain" between 2008 to 2020. The first paper on blockchains was published in the year 2008; hence, we made 2008 a reference year.

Search process: A comprehensive search process was conducted to classify all the primarily available published and catalogued research articles relevant to the research topic of interest. The list of synonyms, abbreviations, and alternative words of the major terms are reported.

The keywords and their synonyms were based on the existing literature in the domain of blockchain and food supply chains. The major keywords and their synonyms were concatenated with the help of "OR" and "AND" operators to construct the search strings that were used for the identification of relevant primary studies.

Inclusion and exclusion criteria: To the best of our knowledge, all published studies in journals, conferences, symposiums, and books related to blockchain technology and its applications, and to the service management and event management process in the food industry were included in the study. Considering the early stage, the study also included workshops, white papers, experience/business/technical reports, presentations, and bulletins. Research studies that did not explicitly discuss food in the context of blockchain technology and IoT were excluded. We also excluded master and PhD dissertations that were not published in journals or conferences. Furthermore, all informal literature surveys were excluded. Duplicated articles were not considered. Additionally, those articles that were reported in languages other English were also excluded.

(ii) Conducting the review:

Identification of research. Primary articles were selected according to the above-listed search string with the following combination of keywords and inclusion of the study in one of the global databases listed below after the keywords.

Search string, which was prepared for keywords search used for the study, is as follows: “blockchain” OR “blockchain technology” AND “food” AND “supply chain” OR “logistics” AND [“food industry” OR “agrifood” OR “agri-food” OR “agriculture” OR “food supply” OR “food supply chain” OR “food ecosystem” OR “blockchain ecosystem” OR “food safety” OR “food security” OR “food waste” OR “traceability” OR “transparency” OR “ERP” OR “enterprise resource planning” OR “internet of things” OR “IoT” OR “blockchain of food” OR “food processor” OR “supply chain collaboration” OR “food Blockchain” OR “food blockchain participants” OR “food fraud” OR “food scandal” OR “food recalls” OR “standards” OR “architecture” OR “smart contracts”].

The following thirteen integrated digital databases that cover heterogeneous disciplines were used to collect the research articles, conference papers, books, and book chapters: ABI/Inform Complete/ProQuest, IEEE Xplore, ACM Digital Library, EBSCO, Springer Link, Wiley, Taylor & Francis, Jstor, Science Direct, Web of Science, Scopus, Google Scholar, and Research Gate. Furthermore, search engines and portals were used to find information on “food” and “blockchain” in white papers, workshop papers, reports, and presentations for the study: www.google.com, www.bing.com, www.yahoo.com, www.ask.com, www.yandex.com, www.linkedin.com, www.theconversation.com, www.forbes.com, www.theguardian.com, www.ibm.com/blogs/blockchain/, www.newfoodmagazine.com, www.globalfoodblockchain.org, www.agroconnect.nl, www.foodsafetynews.com, and www.economist.com. In addition, some webpages were searched in order to collect information on the recent developments of blockchain start-ups in the food industry: Arc-Net (www.arc-net.io), Filament (www.filament.com), SkuChain www.skuchain.com), FarmShare (www.farmshare.us), Agridigital (www.agridigital.io), Origen Trail (www.origin-trail.com), Agriledger (www.agriledger.com), Farm2Kitchen (www.farm2kitchen.com), Provenance.org (www.provenance.org), Chainvine (www.chainvine.com).

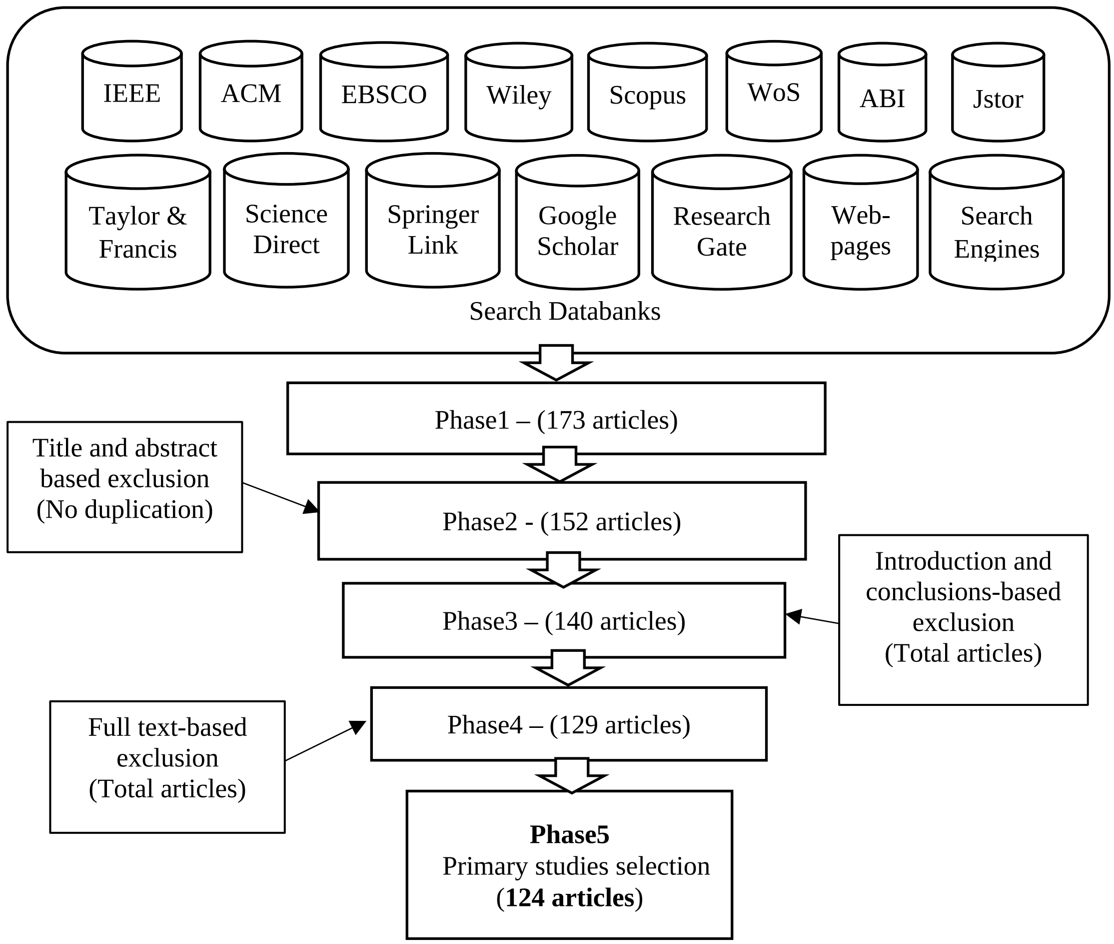

Figure 3: Tollgate approach for article selection

Selection of studies: Here, a tollgate approach with five phases in accordance with Khan et al. (2017) was used to narrow down and to select the most relevant primary studies as shown in Figure 3. The details of the five phases are explained. In Phase 1, the search was carried out using keywords or strings, which resulted in 173 articles. In Phase 2, scanning of titles and abstracts using inclusion/exclusion criteria made it possible to remove duplicate articles thereby reducing the sample to 152 articles. In phase 3, the introduction and conclusion sections of 152 articles were evaluated using inclusion/exclusion criteria, which made it possible to remove an additional 12 articles thereby reducing the sample size to 140 articles. Next, in phase 4, filtering was done by reading the full text as per the inclusion/exclusion criteria, which resulted in a reduced sample of 129 articles. Finally, in phase 5, articles were selected based on primary studies, which resulted in 124 articles identified for further analysis.

Data Extraction: Overall, the literature search using the above tollgate approach resulted in 124 relevant papers. The primary studies considered are listed alphabetically in Table 1. Each paper was read thoroughly by one of the authors to identify the opportunities and impediments of blockchain technology in the food industry. In addition, each paper was categorized according to the PPT aspect, and one more author in the team verified these independently.

Table 1: Primary studies for SLR

#	Reference	Type	PPT aspect	#	Reference	Type	PPT aspect
1	Ahlmann (2018)	JA	People	63	Kshetri (2017)	JA	People
2	Antonucci et al. (2019)	JA	Technology	64	Kshetri (2018)	JA	Process
3	Astill et al. (2019)	JA	Technology	65	Kumar & Iyengar (2017)	JA	Process
4	Azzi et al. (2019)	JA	Process	66	Leng et al. (2018)	JA	Technology
5	Baralla et al. (2019a)	W	Technology	67	Lezoche et al. (2020)	JA	Technology
6	Baralla et al. (2019b)	W	Technology	68	Lin & Liao (2017)	JA	Technology
7	Barnard (2017)	WP	People	69	Lin et al. (2017)	JA	Technology
8	Basnayake & Rajapakse (2019)	CP	Process	70	Lin et al. (2017b)	CP	Technology
9	Bechtsis et al. (2019)	CP	Technology	71	Lin et al. (2018)	CP	Technology
10	Behnke & Janssen (2020)	JA	Process	72	Lin et al. (2019)	JA	Technology
11	Bermeo-Almeida et al. (2018)	CP	Process	73	Liu et al. (2020)	CP	Technology
12	Bordel et al. (2019)	CP	Technology	74	Longo et al. (2019)	JA	Process
13	Brewster (2017)	PR	Process	75	Lucena et al. (2018)	CP	Technology
14	Bumblauskas et al. (2020)	JA	Technology	76	Madumidha et al. (2019)	CP	Technology
15	Burke (2019)	BC	Technology	77	Maghfirah (2019)	JA	People
16	Carbone et al. (2018)	CP	Technology	78	Mao et al. (2018a)	JA	Technology
17	Caro et al. (2018)	CP	Technology	79	Mao et al. (2018b)	JA	Technology
18	Casey & Wong (2017)	JA	People	80	Martinez et al. (2019)	JA	Technology
19	Casino et al. (2019)	JA	Process	81	Mezquita et al. (2020)	CP	Technology
20	ChainLink (2018)	R	Technology	82	Mistry et al. (2020)	JA	Technology
21	ChainTrade (2017)	WP	Technology	83	Montecchi et al. (2019)	JA	Process
22	Charlebois (2017)	Report	People	84	Morkunas et al. (2019)	JA	Process
23	Chen et al. (2017)	CP	Technology	85	Motta et al. (2020)	JA	Technology
24	Chen et al. (2020)	JA	Technology	86	Moudoud et al. (2019)	CP	Technology
25	Cole et al. (2019)	JA	Process	87	Ndraha et al. (2018)	JA	Technology
26	Cottrill (2018)	JA	Process	88	Olsen et al. (2019)	R	Technology
27	Crew (2020)	JA	People	89	Papa (2017)	CP	Process
28	Creydt & Fischer (2019)	JA	Process	90	Patil et al. (2018)	JA	Technology
29	Deloitte (2016)	PR	People	91	Pearson et al. (2019)	JA	Technology
30	Deloitte (2017a)	WP	Process	92	Perboli et al. (2018)	JA	Technology
31	Deloitte (2017b)	WP	Technology	93	Perera et al. (2020)	JA	Process
32	Deloitte (2019)	WP	Process	94	Petersen et al. (2018)	JA	Process
33	Detwiler (2020)	B	Technology	95	Pournader et al. (2019)	JA	Technology
34	DHL (2018)	WP	Process	96	Qian et al. (2020)	JA	Technology
35	Dobrovnik et al. (2018)	JA	Process	97	Queiroz et al. (2019)	JA	Process
36	Duan et al. (2020)	JA	Process	98	Ramachandran (2017)	R	People
37	Dujak & Sajter (2019)	BC	Process	99	Saberi et al. (2019)	JA	Technology

38	Edmund (2018)	JA	People	100	Sander et al. (2018)	JA	Process
39	Ejaz & Anpalagan (2019)	BC	Technology	101	Scuderi et al. (2019)	JA	Technology
40	FAO (2019)	B	People	102	Sengupta et al. (2019)	JA	Process
41	Feng et al. (2020)	JA	Technology	103	Tan et al. (2018)	CP	Process
42	Galvez et al. (2018)	JA	Process	104	Te-food (2017)	WP	Technology
43	Galvin (2017)	PR	Process	105	Tian (2016)	CP	Technology
44	Ge et al. (2017)	R	People	106	Tian (2017)	CP	Technology
45	George et al. (2019)	JA	Technology	107	Tiscini et al. (2020)	JA	People
46	Godsiff (2016)	R	People	108	Tönnissen & Teuteberg (2020)	JA	Process
47	Gopi et al. (2019)	JA	Technology	109	Tripoli & Schmidhuber (2018)	R	People
48	GSMA (2017)	R	People	110	Tsang et al. (2019)	JA	Technology
49	Gurtu & Johny (2019)	JA	Process	111	Tse et al. (2017)	CP	Process
50	Hackius & Petersen (2017)	CP	People	112	van Hoek (2020)	JA	Process
51	Hammi et al. (2018)	JA	Technology	113	Wamba et al. (2020)	JA	Process
52	Hollands et al. (2018)	JA	Technology	114	Wang et al. (2019)	JA	Process
53	Ivanov et al. (2019)	BC	Technology	115	WEF (2019a)	R	Technology
54	Kairos Future (2017)	WP	Technology	116	WEF (2019b)	WP	People
55	Kamath (2018)	JA	Process	117	Xie et al. (2017)	CP	Technology
56	Kamble et al. (2020)	JA	Process	118	Xiong et al. (2020)	JA	Technology
57	Kamilaris et al. (2019)	JA	Technology	119	Xu et al. (2018)	JA	Technology
58	Kaur (2019)	JA	Process	120	Xu et al. (2019)	CP	Technology
59	Kim & Laskowski (2018a)	BC	People	121	Yadav & Singh (2019)	CP	Technology
60	Kim & Laskowski (2018b)	JA	Technology	122	Yiannas (2018)	JA	Technology
61	Kittipanya-ngam & Tan (2020)	JA	Process	123	Zambrano (2017)	WP	Technology
62	Kshetri & Voas (2018)	JA	People	124	Zhao et al. (2019)	JA	Technology

Types of articles: JA: Journal article; CP: Conference paper; B: Book; BC: Book Chapter; WP: White paper; W: Workshop paper; PR: Presentation

Data Synthesis: The analysis of the selected primary studies revealed that the most relevant opportunities to use blockchain technology in the food sector include maintain transparency throughout the food supply chain, accurately track goods, maintain a permanent ledger, reduce costs, decentralize infrastructure, improve efficiency, reduce fraud, enhance security, scale the ecosystem, automate, and innovate. However, in tandem with opportunities, there are several impediments to using this technology. These include complexity of the technology; regulatory implications, such as market regulations; level of trust; implementation challenges; competing platforms; standardization related to data standards and semantics; scalability in terms of performing with very large numbers of transactions; immutability, etc. For example, if data can be updated, then immutability is lost, i.e., if data cannot be updated then how is it possible to deal with changes in the real world; for example, transaction speed, such as throughput; transparency, such as transparency in data with stakeholders to maintain business confidentiality; level of transparency; digitalization; training; awareness; and too many choices limit the use of this technology.

(iii) Reporting and dissemination:

The selected articles are reported according to publication year, type of article, and as per PPT model classification category, as shown in Figure 4, Figure 5, and Figure 6 respectively. Blockchain research in the food field has been attracting interest from researchers as the number of publications is growing yearly, and almost 58% of the selected papers are research articles. Most of the papers studied the technology aspect of blockchains, 52% of papers are technology-oriented papers, 32% focus on process, and 16% focus on people. Based on this review, it is understood that blockchain technology could improve the traceability of shipments by providing better access to information and allowing food providers to identify the precise point of any contamination before it causes further loss in revenue or results in waste products. Thus, food security leads to low transaction costs and instantaneous application. Attaching unique digital identifiers to food products would make them traceable throughout the supply chains, such as origin of products, growth conditions, batch numbers, the factory they come from, processing methods, expiration dates, temperature during storage, and even the distribution details. The in-depth review of selected articles according to the PPT aspect with the limitations/benefits of blockchain technology is listed in Appendix I.

Specifically, the review studies classified the sample as per PPT model, including challenges in each category, and its benefits in terms of performance, including operational benefits concerning waste and safety. The review found several challenges in the people category, specifically, lack of skills, lack of motivation, lack of governance structure, and lack of collaboration. In the process category, our study finds challenges related to operational control in the food supply chain, operational standards, and best practices. The performance benefits listed in the category include traceability-related decisions and swift operations. From the technological perspective, the challenges listed by previous studies are initial cost of implementation, time concerns to complete the implementation, technological protocol, maturity of technology concerned with life cycle, and security risks. The performance benefits include sophistication offered through novel technologies, role of tools, and changes in approach.

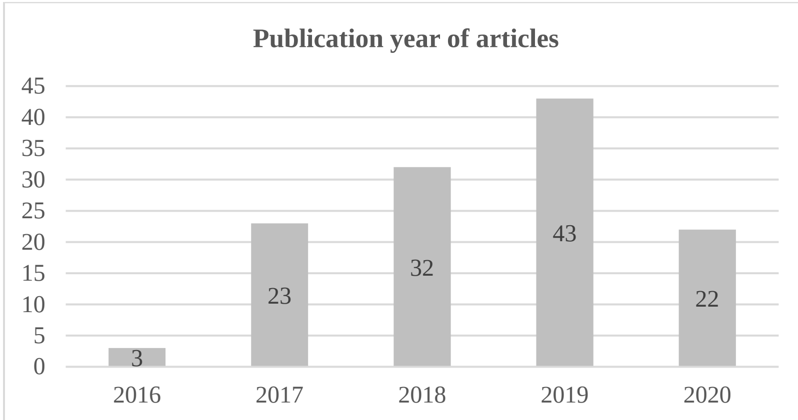

Figure 4: Publication year of the article

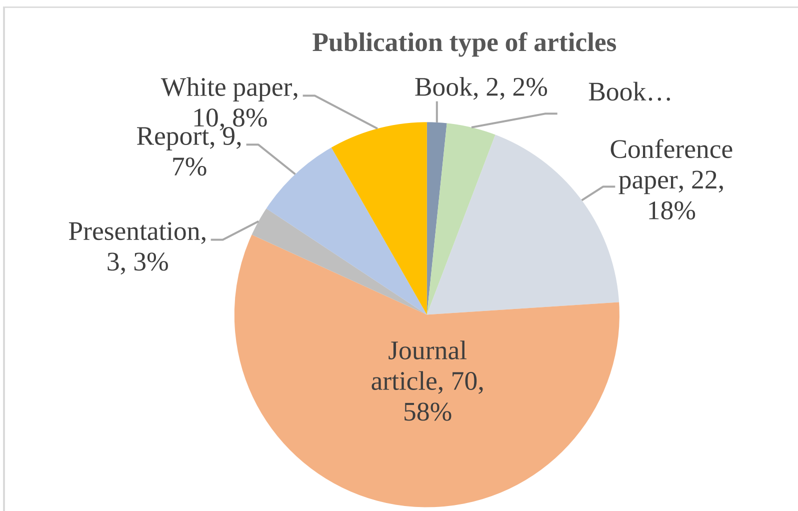

Figure 5: Article classification as per source

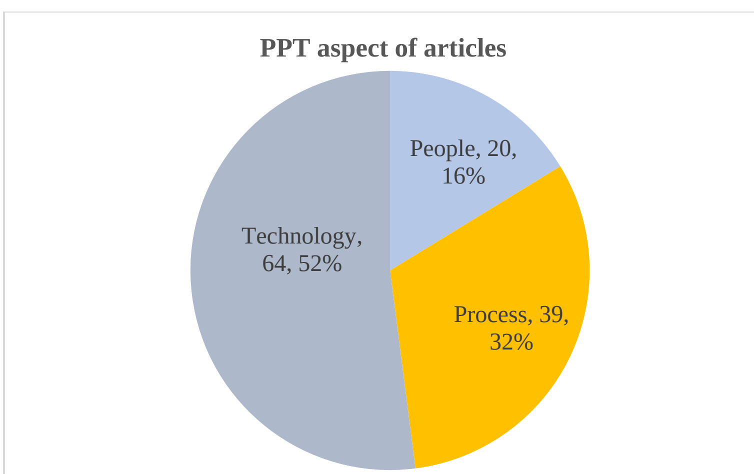

Figure 6: PPT aspect of articles

3.2 Case interviews

To study the strategic challenges with respect to PPT, qualitative data were gathered through semi-structured interviews. As implementation of blockchain technologies is a niche and emerging area of research, we chose qualitative analysis as a methodology to address the research objectives of this study. Interview is a primary method of data collection in a qualitative study (Hatch, 2002). The questions for the interview were prepared after identification of the relevant research gaps in the literature. Semi-structured interview questions were used to explore opportunities, impediments, and implementation issues for blockchain technology implementation in the food supply chain.

The participants included experts / stakeholders from the food industry who had an in-depth knowledge of tracking and tracing technologies and, to a certain extent, had a working knowledge of blockchain technology, or they were blockchain experts who had an awareness about the food sector. A semi-structured questionnaire was developed with twelve major questions. The questionnaire covered open pragmatic questions related to food and blockchain challenges, and opportunities in the four categories of technology, people, process, and performance. Blockchain technology is quite new, and only several companies have any idea about its potential and applications. Therefore, the convenience sampling technique was used to choose the companies. These companies were selected because of their proximity and accessibility (Bryman & Bell, 2015) to two of the authors of this paper. Previous studies suggested selecting cases that have a potential to help and contribute to the research objectives (Subramanian et al., 2020). Hence, the convenience sampling method has been used in many of the recent studies (Batista et al., 2019; Jasimuddin & Naqshbandi., 2019). Twelve semi-structured interviews were carried out in the leading technology and food chain companies over a period of several months from 01.04.2018 to 31.01.2019 in Turkey and India. Nine out of the twelve interviews were carried out in Turkey and the rest in India. In qualitative research, the sample size of 12 is considered to be sufficient for analysis, and qualitative studies have been published with sample sizes of even less than 10 (Krueger et al., 2014; Ramanathan et al. 2017; Kurpjuweit et al., 2019)

The respondents for the study from Turkey were from the business network of the first author. The companies were selected carefully on the basis of professionalism, knowledge, and experience.

All associated companies were part of the food chain either as primary producer or technology provider since food blockchain technology was considered by big companies as a future scalable solution; hence, the interviews were carried out only with medium- or large-sized enterprises. The headquarters of all companies are located in Istanbul and Delhi. The semi-structured interviews were carried out through company visits, and each interview lasted almost three hours. The respondents who participated in this study were experienced professionals who were either expert in technology solutions with a good awareness of the food chain or vice versa or had in-depth knowledge of both. Seven experts were from the food sector and five were from the technology sector. The average length of experience of respondents who participated in the study was 16 years. In terms of level of education, the respondents possessed postgraduate degrees. The profiles of the respondents and the corresponding firms from Turkey involved in the interviews are shown in Table 2a.

The potential respondents for the study from India were selected through a LinkedIn search. The search was made based on the such as “Food supply chain” and “Blockchain”. Since blockchain technology is at a very nascent stage in India, very few professionals were engaged with the technology, and the search identified only a few. Finally, three people agreed to participate in the research and provide relevant input for this study. The average length of experience of the respondents was 25 years. Two of the respondents were postgraduates and one was a graduate in terms of education. Two respondents had medium exposure of blockchain technology, and one had low exposure. The profiles of respondents and the corresponding firms involved in the study are shown in Table 2b.

Table 2a: Basic profile of experts and organizations involved in study (Turkey)

Profile of expert	Experience	Company profile	Company size	Nature of firm
Cold logistics manager	22 years	Food traceability	Medium	Technology
Manager (Information & communication technology	20 years	Technology for IT solutions	Large	Technology
Manager (Information & communication technology)	17 years	Fresh food	Large	Food
Software developer	7 years	Food traceability solutions	Large	Technology
Blockchain expert	20 years	Blockchain solutions	Medium	Technology
Project manager	11 years	Frozen food	Medium	Food
Business development manager	15 years	Dairy products	Large	Food
Supply chain and business development director	16 years	Fresh food retailer	Large	Food
Logistics manager	20 years	Temperature controlled logistics	Large	Food

Table 2b: Basic profile of experts and organizations involved in study (India)

Supply chain and operations head	25 years	Food industry	Large	Food
President	30+ years	Seasoning and flavours	Large	Food
Business head - distribution	20 years	Cold chain solutions	Large	Technology

During the interview, the experts were asked twelve questions as shown in Appendix II. The first question was associated with awareness of food safety scandals, such as the horsemeat scandal, salmonella outbreaks, and so forth. The other questions were asked in order to understand participants' perceptions and experiences of the ways in which, for example, they find the implementation challenge of blockchains, or companies' Information and Communication Technologies (ICT) requirements to adapt blockchain technology. All interviews were recorded.

4. Findings

A blockchain consortium brings like-minded organizations together and enables a new level of trust and transparency based on a single view of the truth; therefore, blockchain consortium are the widely accepted and appropriate models for use in business. From this aspect, further investigation is needed to understand if consortium blockchain technology might be the most suitable supply chain collaboration method in the food industry for food tracking and traceability, which enables a safer, more affordable, and more sustainable food system. A successful integration of the blockchain requires the engagement of all participating organizations including farmers, suppliers, and retailers (Charlebois, 2017). In order for goods to be traceable from farm to fork, all parties that handle the products should be linked to the blockchain. The key opportunities and impediments from the participants' responses are summarized in Table 3.

Overall, from Table 3, it is clear that opportunities and impediments are more in the people and technology perspectives. As expected, it is still too early to figure out the opportunities and impediments in the performance perspective. Interestingly, we did not see many issues in the process perspective. Measuring food loss, standardization, and regulatory and legal acceptance are the immediate opportunities for people to consider in the process perspective of the application of blockchain technology in the food sector. Temperature management, validation, and standardization are potential avenues for future researchers.

There is quite a high number of opportunities in the people perspective, of which redistributing surplus food, increasing customer loyalty, resisting corruption, reducing overall food price, and espousing anti-authoritarian protopia with a free decentralized society will lead multiple stakeholders to espouse blockchain technology in the future. However, if the community as a whole can focus on preparing competent manpower, creating a recognized consortium, and developing regulations to satisfy customer demand, then most of the people issues can be handled without any resistance to change.

On the technology front, there are a number of impediments since blockchain technology as a whole is new to the food chain. Hence, there are several technical issues that need to be resolved before it can be realised in practical terms. These include issues such as data capture, network maintenance, enterprise architecture model, interoperability between cold chain and blockchains, etc. Among all the above, it is interesting to note that the massive requirement of infrastructure and security will boost the usage of blockchains widely in the food sector. From the opportunity point of view, it is clear that there are massive benefits that outweigh the risk in the implementation.

Table 3: Issues in Blockchain enabled food supply chain

Opportunities	**Impediments**
Table 3a: Process issues in Blockchain enabled food supply chain	
• Regulatory and legal acceptance • Standardization and customisation (product, service, information technology and packaging) • Keeping track of food loss. If we have data to analyse where food loss happens, we will have the ability to stop or decrease it dramatically	• Freezing temperature management in terms of excess standard and market values, spoiled milk and meat, salmonella-contaminated cheese, coliform bacteria in food or beverages • Validation and standardization research
Table 3b: People issues in blockchain-enabled food supply chain	
• Redistribution of surplus food • No manipulation, cryptology, reduction of transport, storage, handling cost, time and increase in quality • Understand food loss and waste • Customer loyalty, credibility & reduced costs • Traceability and transparency • Corruption resistance, traceability, authenticity, disintermediation, robustness, confidentiality • Better bullwhip effect • Openness culture anti-authoritarian; espousing protopian dreams of a free and decentralized society	• Skilled personnel are required • Unique digital identifiers • Standards • Trustworthy consortium. • Additional investment to work with other party • Regulations and customer demand • Validation, standards and regulation • Intellectual rather than technological transformation, so takes time
Table 3c: Technology issues in Blockchain enabled food supply chain	

• Risk benefit will favour blockchains in terms of transparency and traceability • Need-based analysis • Database is used as a client-server network architecture • Standalone blockchains for specific purposes • ERP complementarity Enterprise chain infrastructure	• Legal and security integration is not clear • Lack of common technology • No central administration • Interoperability • Reliable data capture system, such as 5G technology • Mining pool, consensus protocols, and hashing algorithms for the data access layer need to be arranged • Technological capabilities (bandwidth etc.) are required for interconnections. • An enterprise data architecture model is required • Radio access network, transmission network, and IP backbone network are required • For the application layer, both web and mobile applications are required • ICT system needs to establish a link between blockchain and ERP systems to transfer the data to the inbound systems. • ICT and cold chain should talk to each other. • Customization of ERP in a food chain is difficult; backward and forward lot traceability • Capacity shortages and other difficulties can be tracked and managed in a timely fashion. • Maintaining a blockchain network • Blockchain implementations mostly done in C++ which is not a very friendly programming language for developers Current bitcoin mining reward for adding a block to the chain is 12.5 + transaction charges (nearly between 13 to 14 Bitcoins). So technically, 12.5 bitcoins are being created out of thin air every 10 minutes.
Table 3d: Performance issues in blockchain-enabled food supply chain	
• Compliance at micro level delivery time, lot size, storage and transport conditions.	• Performance (latency, speed): • Fresh preservation compliances

5. Discussion and framework

Interaction of blockchain technology with people, process, and performance has several challenges. Typically, blockchain technology implementation has to learn from ERP implementation, which is an expensive solution, and it should be customized according to the needs of an enterprise. Customization of ERP implementation is a major challenge in the food chain, as there are different types of products, and even the quality requirements for the same product (i.e., tomatoes) may differ. There are specific order processing modules for every product, which depend on the product requirements. Backward and forward lot traceability is another challenge.

An ICT system needs to establish a link between the blockchain technology and ERP systems to transfer the data to the inbound systems. For the application layer, both web and mobile applications are required. A mining pool, consensus protocols, and hashing algorithms for the data access layer need to be arranged along with the smart contracts and cryptographic signatures. Smart contracts can automate quality control criteria.

The value achieved through integrating the blockchain technology with ERP systems comes not by creating and importing new information into the distributed ledger but by drawing existing data from the enterprise systems and being able to tightly control with whom it is shared. Certainly, blockchain technology will be a complementary product for the ERP system.

The four perspectives from our analysis clearly indicate numerous impediment issues with respect to the people and technology perspectives. In general, the PPT model has been strategically used in different fields to enhance the quality of performance; in particular, there is evidence to suggest that data quality improves if there is proper blending between the three (Monterio, 2016). Our findings based on the SLR and interviews illustrate the requirement of interaction of blockchain technology to enhance the relationship between the people and the process as well as between the process and the food supply chain performance. Overall, there is stronger evidence to suggest that balancing the relationship between the people and technology elements would significantly improve the performance. Similarly, blending the process and technology elements would minimise the errors and improve the performance of the food supply chain. The intervention of technology will have a stronger influence in the relationship between people’s involvement and the process requirements as well as the relationship between the process requirements and the expected performance. Hence our research propositions for the study are as follows:

P1: Interaction of blockchain technology with the people and process relationship will improve the food supply chain performance.

P2: Interaction of blockchain technology with the process and performance relationship will improve the food supply chain performance.

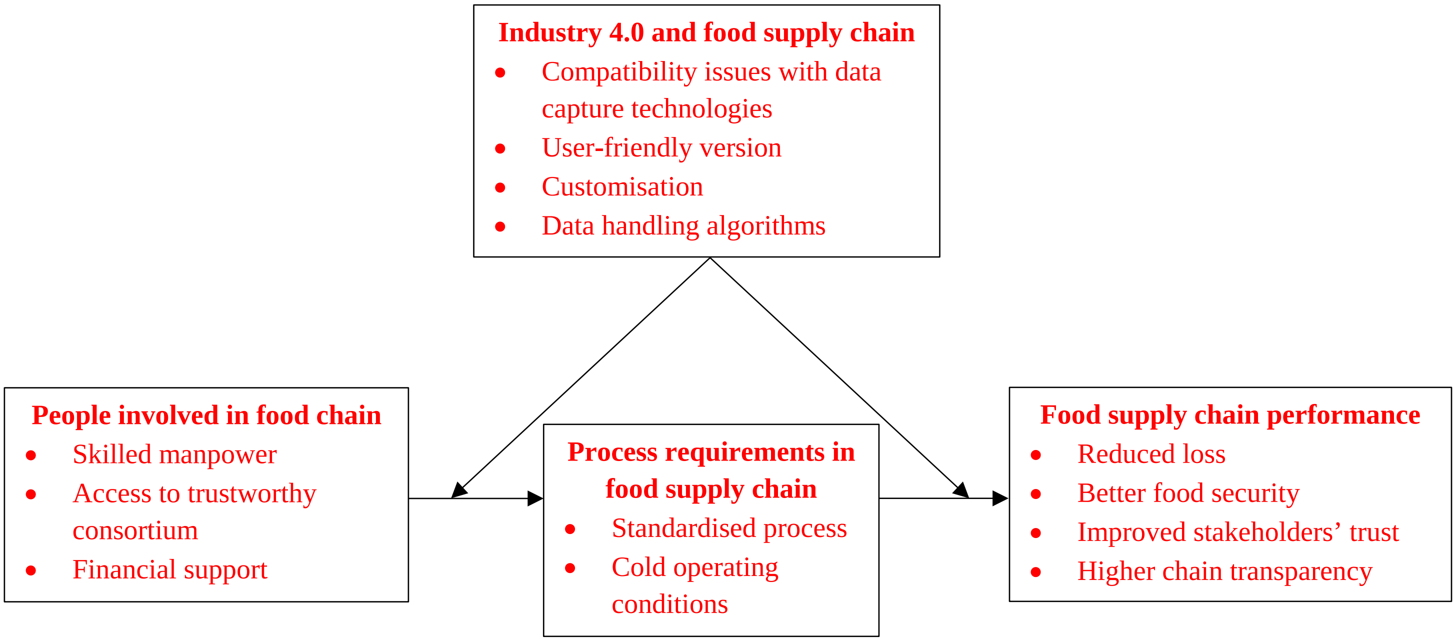

Figure 3: Blockchain-based PPT model for better food supply chain performance

The blockchain-based PPT model for food supply chain performance is shown in Figure 3. Further, this model is derived from data derived from several interviews conducted in emerging economies, such as Turkey and India, and needs to be tested using large-scale empirical data. Moreover, blockchain technology in the food industry has considerable potential to enhance traceability, transparency, and confidence, but substantial academic work is required, as there are many technical problems and obstacles. The technology transfers more business relationships into code (law). Industry public leaders and should embrace the blockchain technology as an opportunity, and it should be added to the digitalization strategy currently affecting the entire food industry. Stringent regulations at both the national and the international level need to be implemented. The transparency, productivity, competitiveness, and sustainability of the food industry need to be enhanced. The technology will play a major role in the food supply system, but right use cases (meat, dairy, fish, fruit, and vegetable products) need to be established. Nonetheless, the research should investigate how to generate evidence-based blockchain solutions for the entire food system.

6. Conclusion

A supply chain starts with a raw material and ends up with a product to be served to the customer. In between, there are many intermediaries. We usually trust the product and the company that produces the product or services. In the era of Industry 4.0, blockchain can eliminate the trust factor without anyone actually knowing the real situation. Blockchain technology enables trusted data storage with built-in privacy and management. The main purpose of using blockchain technology is security. Blockchain technology also improves supply chain transparency and chain of custody.

Our study answered the major research questions such as opportunities and impediments to implement blockchain technology in the food supply chain and the specific implementation issues at the micro level, such as people, process, technology, and performance. Typically, blockchain technology will ensure the non-manipulation of data, transparency, security, and collaboration among the stakeholders. The study contextualizes PPT theory in an emerging economy to show the interaction effect of technology to strengthen the relationship between people, process, and performance. Specifically, the four constructs include opportunities, impediments, and specific implementation issues of blockchain technology in the food supply chain from the actual experience of professionals in Turkey and India. The study can help managers in the food supply chain to leverage opportunities with the learning from emerging economy perspectives.

All the parties in a blockchain have a responsibility to distribute the right information. The retailer can monitor the current capacity of producers and be connected directly to make the new orders using the whole traceable system that makes it possible to collect the relevant information, like delivery time, lot size, and storage and transport conditions. Also, IoT devices need to be implemented throughout the food supply chain in order to capture comprehensive and consistent data across multiple parties and transmit the data to the blockchain. IoT devices can capture data for every parcel (pallet) of product, not just for a sample, while IoT answers questions of where, when, and what happened in the supply chain. The right application of IoT and blockchain technology can transform the supply chain, giving manufacturers and retailers the opportunity to succeed at both.

This study has several limitations, which can be addressed by future researchers. In this study, we have focused on the food supply chain as a whole. However, the opportunities and impediments may change according to the type of food supply chain. This work is based upon the inputs from a few professionals in the food supply chain. The model proposed in the study needs to be validated using large-scale empirical evidence from both developed and developing countries. Future studies can also analyse the innovation diffusion of blockchain technology in contextualised supply chains and advance the knowledge of innovation and technological advancement.

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Appendix I – Issues identified related to blockchain in FSC from SLR

People
<u>Lack of skills:</u> • lack of knowledge and engagement to blockchain technology and how to benefit from blockchain technology lead slower adoption (Ge et al., 2017; Ahlmann, 2018). • Lack of awareness (Ramachandran, 2017; Hackius & Petersen, 2017; Edmund, 2018; WEF, 2019b) • Lack of impartial education (Kshetri & Voas, 2018; WEF, 2019b) <u>Lack of motivation:</u> • lack of facilitation and encouragement of value chain partners (notably smallholder farming) does not provide genuine and precise information to blockchain ledger. Blockchain adoption of one farmer can exert normative pressure on the other members of FSC (Kshetri, 2017). • Enabling transparency in FSC through implementation of blockchain and other technologies requires considerable effort from all participants involved (Ahlmann, 2018; Ramachandran, 2017). <u>Lack of governance</u> • Lack of noneffective governance may lead the biggest obstacles for nonprivate, non-hierarchical ledgers (Ahlmann, 2018). All blockchain powered FSC participants need to mutually agree on governance and consensus rules. <u>Lack of collaboration</u> • Participants needs to willingly share data and be open to collaborate (Crew, 2020). Blockchain leads strategic coopetition in each level of FSC (Ahlmann, 2018).
<u>Anti-corruption and anti-food fraud:</u> • Blockchain provides opportunities such as transparency and fraud reduction, public safety, controlling financial waste or corruption and legal property improvement (Kshetri & Voas, 2018; Tripoli & Schmidhuber, 2018; Tiscini et al., 2020), internal external auditing, administrative and operations cost reduction, payment verifications and contract validity (Deloitte, 2016; Kshetri, 2017) by allowing all members of an FSC community to monitor the activity of each other's credentialed staff (Casey & Wong, 2017). <u>Benefit to agriculture finance:</u> • Blockchain solutions support farmers for transaction and payment side, crop insurance, microfinancing, improving farm production yields, delivering vaccines, or increasing access to education (Kim & Laskowski, 2018a; Tripoli & Schmidhuber, 2018; Maghfirah, 2019) • Creating economic identities for smallholder farmers (GSMA, 2017) • Faster and fairer payment to all members of FSC from farm to fork (Charlebois, 2017; FAO, 2019; Maghfirah, 2019; WEF, 2019b; Crew, 2020) • Disadvantaged groups (refugees, displaced persons) for payment and food supply (Godsiff, 2016; Kshetri & Voas, 2018) • Farmland registry on blockchain and crowdfunding livestock (Deloitte, 2016)
Process
<u>Lack of operational controls in FSC</u> • Lack of controlling time, temperature and tolerance effects in ensuring the food safety and food quality along the FSC processes (Tian, 2016). • Lack of operational capabilities (Deloitte, 2019; Kamble et al., 2020) • Lack of food integrity, security and transparency (Brewster, 2017; van Hoek, 2020)

Lack of standards in FSC

- Missing standards for the level of detail of traceability (Deloitte, 2017a; Behnke & Janssen, 2020)
- Lack of standardization of internal processes in terms of critical traceability points and traceability data (Behnke & Janssen, 2020)
- Compliance with special quality requirements for food products (Behnke & Janssen, 2020)
- Standardization of quality requirements among all participants in FSC (Galvez et al., 2018; Behnke & Janssen, 2020)
- Low ICT penetration (Brewster, 2017; Dujak & Sajter, 2019; Duan et al., 2020)

Lack of best practices

- lack of studies explaining or evaluating blockchain (Dobrovnik et al. 2018; Cottrill, 2018; Cole et al., 2019; Queiroz et al., 2019)
- lack of empirical evidence (Cottrill, 2018; Galvez et al., 2018; Cole et al., 2019; Creydt & Fischer, 2019; Queiroz et al., 2019; Tönnissen & Teuteberg, 2020)
- lack of comparison with successful or unsuccessful technologies (Cole et al., 2019)
- stakeholder cooperation (Kamath 2018; Dobrovnik et al. 2018; Creydt & Fischer, 2019; Duan et al., 2020)
- blockchain's entry point to FSC is difficult to identify (Dobrovnik et al. 2018; Wang et al., 2019; Perera et al., 2020)
- impact on current business models is unknown (Tönnissen & Teuteberg, 2020)

Benefit to tracking and traceability

- Ensuring full transparency of FSC processes builds consumer trust for food products (i.e. organic food and fair-trade labelled products) as well as for food safety (i.e. protecting consumers from food borne diseases or health hazards) and increase ultimately confidence for the agri-food markets (Tian, 2016; Tan et al. 2018, Azzi et al., 2019; Basnayake & Rajapakse, 2019; Creydt & Fischer, 2019; Kaur, 2019; Morkunas et al., 2019; Montecchi et al., 2019)
- In-time detection of mistakes or errors coming from any part of FSC in case of occurring unsafety operating incidents (Kumar & Iyengar, 2017; Sengupta et al., 2019; Tse et al., 2019)

Benefit to certification

- quality or origin and food farmers certifications through blockchain (Papa, 2017; Basnayake & Rajapakse, 2019; Petersen et al., 2018).
- Cascading of certification and revocations (Brewster, 2017; Sander et al., 2018)
- Quick response code embedded smart contracts identifies food product and farmers practically and cost effectively farm-to-fork assessment (Sander et al., 2018; Basnayake & Rajapakse, 2019)

Benefits to swift operations

- blockchain technology in FSC for the products (i.e. canned tuna, poultry meat) validate supplies and upstream operations swiftly and efficiently (Bermeo-Almeida et al., 2018; Longo et al., 2019; Kittipanya-ngam & Tan, 2020; Perera et al., 2020)
- proving authenticity against dishonest transaction (Tse et al. 2017; Creydt & Fischer, 2019)
- effect food supply chain performance metrics (Kshetri, 2018; Casino et al., 2019; Cole et al., 2019; Gurtu & Johny, 2019; Kamble et al., 2020)
- Automating commercial processes (i.e. recall) and trade promotions (Galvin, 2017; DHL, 2018; Longo et al., 2019, Wamba et al., 2020; Perera et al., 2020)

Technology

High cost and time concerns:

- There are high costs (i.e. investment) and data processing time for the integration of blockchain into the existing FSC traceability system. (Tian, 2017; Lin & Liao, 2017; Lin et al. 2017; Pearson et al., 2019; Chen et al., 2020)

• The on-farm data (i.e. DNA of livestock animals) uploaded to blockchain-powered FSC can be expensive. (Gopi et al., 2019; Xiong et al., 2020) • Transparent food production systems require rapid data exchange between stakeholders which leads to expedition of processes and transactions times (Astill et al., 2019). <u>Lack of standards</u> • lacking uniformed technology standard makes adoption difficult (Zhao et al., 2019; Chen et al., 2020; Feng et al., 2020). • the ownership of the maintenance responsibility and task (Antonucci et al., 2019; Deloitte, 2017b) • need for the alignment on standards and technology infrastructure (WEF, 2019a; Scuderi et al., 2019) • required tamper-proof metadata infrastructure in order to adapt changing environments and regulations (Tian, 2017) <u>Immaturity of technology:</u> • the speed of blockchain based transaction for storage and synchronization, scalability in terms of throughput, latency, and capacity (Tian, 2017), interoperability (Feng et al., 2020), architecture for security features, limited transactions (Burke, 2019; Pearson et al., 2019) are major concerns to integrate blockchain with current FSC network (Yadav & Singh, 2019, Zhao et al., 2019) • using blockchain and mobile apps runs on smartphones. The lack of access to mobile networks is the main constraint from farmer side to interrupt farm-to-fork data flow and food safety. Zambrano (2017) • blockchain adoption requires seamlessly integration with the existing database and legacy systems such as ERP, WMS, MES (Hollands et al., 2018; Perboli et al., 2018; Baralla et al., 2019a; Pearson et al., 2019; Martinez et al., 2019; Xiong et al., 2020) • blockchain requires more effective consensus mechanism to handle large number of nodes and resources stored in blockchain platform (Tsang et al., 2019; Zhao et al., 2019; Feng et al., 2020) • the primary realization of the infrastructure with different smart contracts and responsible (governmental or certified third party, etc.) (Antonucci et al., 2019; Baralla et al., 2019a) • scalability obstacles in blockchain protocols (Lin et al. 2017; Chen et al., 2020) • product complexity makes tracking difficult on blockchain platform (WEF, 2019a) • associated technologies (i.e. sensing) for automated data transaction to blockchain need to be developed further (WEF, 2019a; Pournader et al., 2019) <u>Security risk</u> • cyber threats, cyber security risk, needs to improve base knowledge and technical assistance (Xu et al., 2018; Antonucci et al., 2019)
<u>Benefit to tracking and traceability</u> • trusted/authorised users verify the traceability and authenticity of the product at any point of FSC through blockchain adoption. (Tian, 2016, Tian 2017, Yiannas, 2018; Hammi et al., 2018; Ndraha et al., 2018), so that consumers can obtain the full information of the product in the whole FSC (Tian, 2016; Kairos Future, 2017; Carbone et al., 2018; Bordel et al., 2019; Chen et al., 2020; Liu et al., 2020) • Using smart contracts links up each process among food traceability stage (Lin et al., 2017; Lin et al., 2017b Baralla et al., 2019a; Pournader et al., 2019; Motta et al., 2020) • allowing the verification of the integrity of data sworn by each authorized user in FSC (Baralla et al., 2019a). • blockchain based quality assurance tracking enables same business rules and transaction data while reducing disputes among business partners, information asymmetries and consequently improving governance (Lucena et al., 2018; Perboli et al., 2018, George et al., 2019) <u>Benefit to integration of new technologies</u> • blockchain-based traceability system performs better with involving different technologies such as IoT (Christidis & Devetsikiotis, 2016; Caro et al., 2018; Hammi et al., 2018; Lin et al., 2018; Madumidha et al., 2019; Ivanov et al., 2019; Mistry et al., 2020), AI (Qian et al., 2020), unique identifiers such as RFID (Lin et

al., 2017b ;Tian, 2017; Ejaz & Anpalagan, 2019; Gopi et al., 2019; Tsang et al., 2019) and QR code, NFC (Tsang et al., 2019), WSN, GPS (Chen et al., 2017), CPS and industrial information integration (Xu et al., 2019), fog/edge/cloud computing (Carbone et al., 2018), big data (Ndraha et al., 2018; Astill et al., 2019), 5G (Mistry et al., 2020) and food-sensing technologies (WEF, 2019a) which have a great impact on the reduction of uncertainty, time consuming workflows and significant costs in FSC processes (Hollands et al., 2018; Zhao et al., 2019; Kamilaris et al., 2019; Saberi et al. 2019; Lezoche et al., 2020; Detwiler, 2020).

- Integrating blockchain technology with edge/cloud computing (SaaS) can achieve a higher-level knowledge sharing performance (i.e. automated recall, provenance assurance) through developing a distributed, sharing, standardized, and secured framework (ChainTrade 2017; ChainLink, 2018; Zhao et al., 2019)
- smart contracts automate the storage of product information related to the FSC (Te-food, 2017; Mao et al., 2018a; Mao et al., 2018b; Baralla et al., 2019b; Moudoud et al., 2019).
- use of innovative information technology-based solutions can be the safeguard to protect especially perishable food (Bechtsis et al., 2019; Mistry et al., 2020).

<u>Benefit to integration of tools and approaches</u>

- using informal or semi-formal ontologies have greater impact for developing and operating blockchain to ensure better data standards, business practices and processes (Kim & Laskowski, 2018b)
- FSC system with double chain architecture based on blockchain guarantees transparency, data safety, privacy of enterprise information as well as improves the credibility of service platform and overall efficiency of the system (Xie et al. 2017; Hollands et al., 2018; Leng et al. 2018; Mao et al., 2018a; Mao et al., 2018b; Moudoud et al., 2019; Bumblauskas et al., 2020; Mezquita et al., 2020).
- An ICT e-agriculture system with blockchain infrastructure improves economic efficiencies, food safety with Quality of Experience (QoE) metrics based on food provenance and traceability (Carbone et al., 2018) and reduces uncertainty risk as while achieving sustainable agricultural development (Xie et al. 2017; Lin et al., 2017; Lin et al., 2019).
- Remote monitoring and automation improve reliability and enable faster and efficient operations and scalability (Patil et al., 2018; Mistry et al., 2020)
- Using API (Pearson et al., 2019; Olsen et al., 2019), REST interfaces, NoSQL databases and Java-Script code (Bordel et al., 2019), encrypted biometrics (Xu et al. 2019) it is implemented a distributed solution to collect, sign and store trustworthy information about the food product flow

Appendix II – Questionnaire for case interviews

Questionnaire

Demographic data

1. Respondent position:

2. Total years of experience: Technology: Food:

3. Your exposure towards block chain: High/medium/low

4. ICT technology implementation experience in years:

5. Educational background

Semi structured interview questions

1. Are you aware of some of the food chain challenges? Say horsemeat scandal, chipotle chain scandal etc.

2. Can you please narrate the Blockchain implementation challenges?

3. You know digital ledger will bring in trust and accountability to what extent these prevent food loss.

4. Based on your view, how do you perceive Blockchain will reduce conflicts and improve collaboration in food chain?

5. Please narrate how Blockchain characteristic will reduce the food loss

6. Can you please let us know the advantage and disadvantages of ERP implementation in the food chain?

7. How will you compare ERP with Blockchain implementation, is it a substitutional or complimentary product?

8. You know food is subjected to several compliance such as safety risks, food security, and traceability. How Blockchain will comply with and reduce the role of intermediaries?

9. Can you please narrate the compatibility issues for companies to migrate towards Blockchain from the existing technologies?

10. What are the major motivators for companies to move towards Blockchain?

11. As you know there will be always a resistance to change to new technologies, in the case of Blockchain what type changes should happen at organizational micro and macro level.

12. Can you explain the essential ICT requirements to deploy a Blockchain solution from the technology provider infrastructure perspective?