# Exploring the potential of blockchain technologies in the food supply chain: opportunities and impediments

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## Abstract
The paper develops a Blockchain enabled food supply chain framework including the future opportunities and the present impediments based on systematic literature reviews and semi-structured case interviews from the emerging economy context. This study further paves way for future researchers to address technological and people related challenges in application of evolving technologies to mitigate the emerging problems in food sector. Interestingly, we didn't find many issues in process and performance aspects. The study will be the first in this context and opens up the discussion for future researchers and list the potential threats as per pseudo anonymity among the stakeholders.

**Keywords:** Blockchain, Food supply chain, Food security, Track and Tracing, Agri-food

### Introduction
Advanced technologies have been adopted in many industries to increase the traceability, but in food industry, it has made a tardy progress, and in particular for creating more secure food supply chains. The food supply chain is facing uncertainties because of product perishability, furthermore, the increasing globalization of food production and trade has opened up access to food and increased consumer options. This makes not only the supply chain longer and more complex, but also, it adds significant tracking and safety challenges which necessitates to change the farm to fork business models (King et al., 2017). Food travels through an often-vast network of farmers, retailers, distributors, transporters, storage facilities, and suppliers before reaching the end consumer that participate in 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. The food tracking enables the supply chain to measure safety of perishable food products tracing its journey from where they were grown, handled or stored, under what condition transported or processed, thus, leading to development of a transparent and authentic chain of records of food ecosystem. In addition, recent developments in technologies prevents unnecessary waste, reduces economic burden of product recalls, cross contamination etc.

One among the technologies that supports transparency and trust issues is Blockchain which can share and decentralize control through a distributed ledger technology. Blockchain is relatively a new technology, but the interest to use the technology among the companies and development of use cases are growing exponentially. As a new

business collaboration tool, Blockchain supports a secure, shared data network and allows untrusted parties to reach consensus on a shared digital history without using a trusted intermediary (Swan, 2015). Hence, from managerial perspective this paper explores the opportunities and impediments of using Blockchain technology in food supply chain.

The study investigates some of the following pragmatic open questions: i) can the basic characteristics of Blockchain technology resolve the challenges as trust, accountability and conflicts in food industry, if so, how? ii) can Blockchain solution strengthen collaboration among the stakeholders? iii) can Blockchain technological solutions be a complementary to existing ERP systems used in food industry? iv) can Blockchain technological solutions meet the requirements of food industry in terms of safety risks, food security, traceability? v) what are the needed ICT requirements to deploy a Blockchain solution in a technology provider infrastructure? Primarily the major contribution of this study is to develop a Blockchain enabled food supply chain framework that classifies the opportunities and impediments as per process, people, technology and performance categories.

**Blockchain technology in food industry**

Blockchain technology is at the early stage of development, however, it has made a great progress since last 4-5 years. The technology was known primarily for being foundation of crypto-currency (bitcoin) but has recently been applied in several industries such as healthcare, finance, insurance, and e-commerce to improve transparency and accountability. In addition to the above benefits, Blockchain technology is also capable to reduce food waste by creation of renewable energy. There are currently only a few Blockchain based pilot applications in food industry, where big companies like Walmart, Nestle, Unilever have carried out pilot project using perishable food products (vegetables, meats) to verify its viability, moreover there are also some newly established Blockchain start-ups such as Provenance and Filament. In order for goods to be traceable from farm to fork, all parties of food supply chain that handle the goods should be linked to the Blockchain and collaborate on a Blockchain consortium to share all food related data (i.e. hazard analysis and critical control point (HACCP) records, quality records, temperature records, humidity records, verification records, tracked food information and so on). The stakeholders involved in the food supply chain from farm to fork are shown in Figure 1 including farmers, distributors, packers, processors, wholesaler, retailer, customers such as grocers, restaurants, traders, and end users jointly act and share food related data using a Blockchain consortium. Blockchain is the core of the solution but it alone isn't enough, it should be used with IoT devices, radio frequency identification, wireless sensor networks and other digital applications. The joint responsibility and transparency benefits food security with low transaction costs and instantaneous application. Blockchain assigns unique digital identifiers to food products including growth conditions, product ID, batch numbers and expiry dates. This would help to prevent food waste, allow consumers to work out the ecological footprint of their food, and guide the distribution of surplus food to those who need it. This shared and immutable register of foods and transactions would prevent fraud and enable source identification of foodborne illness. And as digital technologies are increasingly used to manage farms, Blockchain will promote sharing of on-farm data.

Blockchain technology stores and shares information across a network of users in an open virtual space and it allows users to have a look at all transaction simultaneously and in real-time. Each block contains the data of all transactions in the system within a period of time and it creates 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 proper linear, chronological order with every block containing a hash of the previous block.

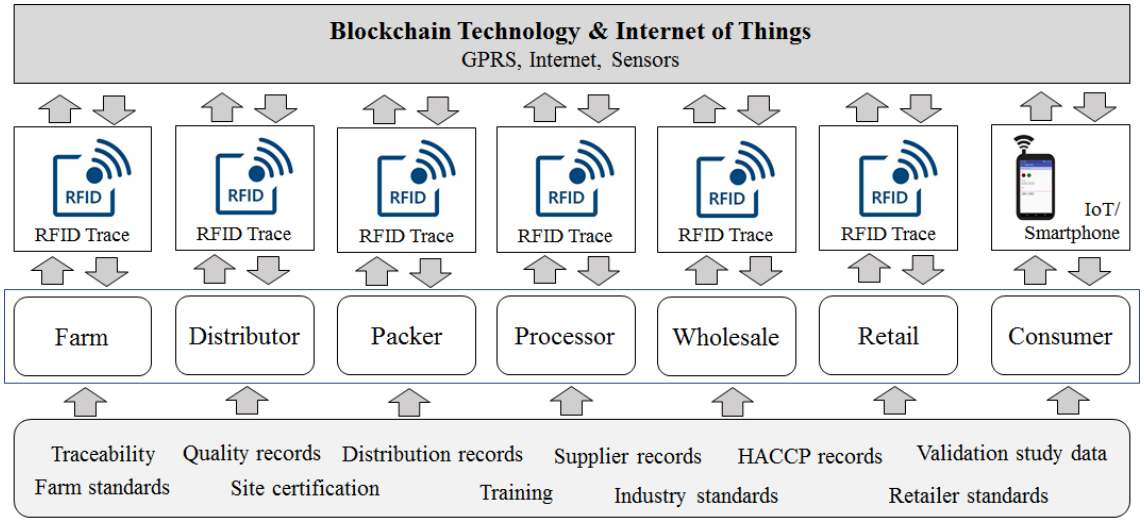


*Figure 1- Blockchain integration in food supply chain*

The development of Blockchain applications also empowers the entire chain to be more responsive to any food safety disasters (i.e. horsemeat scandal, salmonella peanut butter outbreak) in the agri-food industry and prevent food fraud (Crossey, 2017). Blockchain technology offers great potential for food safety and verification in the agri-food industry. In food, for example, a retailer would know with whom his supplier has had dealings. 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 a 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.

**Methodology**

The study uses systematic literature review (SLR) and case interviews to advance the understanding of the opportunities and impediments of using Blockchains in global food chains including all stages starting from farm towards customer end i.e. until fork. Since the technology is at an early stage and there are not many studies it is vital for the study to understand the current impediments and potential research opportunities. Systematic literature review identifies the advancements made in potential application of this technology in the food sector and the case interviews throw insights and stumping block in progress of the application.

*Systematic literature review (SLR)*

A research strategy for SLR is adopted in order to review the most relevant literature. Document analysis method is used to review the primarily published and catalogued articles related to the research topic including: journal papers, conference proceedings, workshop papers, symposium papers and ACM/IEEE bulletins. Considering the early stage this study also included business/technical/experience reports, master/PhD thesis, white papers and the books chapters related to Blockchain technology and its applications, service management and event management process in food industry.

A sample of articles is selected based on the following combination of keywords and inclusion of the study in one of the global databases listed below after keywords. Keyword search used for the study are “blockchain” OR “blockchain technology” AND “supply chain” OR “logistics” OR “food” AND [“food industry” OR “agrifood” 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”]

Search engines and portals used to find information in blogs and white papers for the study are 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, www.economist.com.

Academic articles are retrieved from the following databases: Web of Science (Clarivate Analytics), Scopus (Elsevier), Google Scholar, ProQuest, Research Gate, Science Direct, Ebsco, IEEE Digital Library, ACM Digital Library, Springer Link, Wiley Besides this, the study also checked the recent developments of Blockchain start-ups in 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), Prove-nance.org (www.provenance.org), Chainvine (www.chainvine.com)

Overall the literature search using the above sampling criteria resulted into 30 relevant papers. The paper considered in the sample are listed alphabetically in Table 1. Each paper has been thoroughly read by one of the authors to pick the opportunities and impediments of Blockchain technology in the food industry.

*Table 1 – Sample of studies for SLR*

| # | References | Type of papers | # | References | Type of papers |
|---|---|---|---|---|---|
| 1 | Banerjee (2017) | white paper | 16 | Kewell et al. (2017) | journal article |
| 2 | Barnard (2017) | white paper | 17 | Kim and Laskowski (2018) | journal article |
| 3 | Casey and Wong (2017) | journal article | 18 | King et al. (2017) | journal article |
| 4 | Chain trade (2017) | white paper | 19 | McDermott (2017) | experience report |
| 5 | Charlebois (2017) | experience report | 20 | Nakasumi (2017) | conference paper |
| 6 | Christidis and Devetsikiotis (2016) | journal article | 21 | Ndraha et al. (2018) | journal article |
| 7 | Cottrill (2018) | journal article | 22 | Nowinski and Kozma (2017) | journal article |
| 8 | Crawford (2016) | white paper | 23 | O’Leary (2018) | journal article |
| 9 | Deloitte (2016) | presentation | 24 | Petersen and Jansson (2017) | master thesis |
| 10 | Edmund (2018) | journal article | 25 | PwC (2016) | white paper |
| 11 | Galvin (2017) | presentation | 26 | Ramachandran (2017) | experience report |
| 12 | Hackius and Petersen (2017) | conference paper | 27 | Scott et al. (2017) | journal article |
| 13 | Hannetel (2017) | business report | 28 | Swan (2015) | book |
| 14 | Iansiti and Lakhani (2017) | journal article | 29 | Te-food (2017) | white paper |
| 15 | Kairos Future (2017) | white paper | 30 | Tian, 2016 | conference paper |

*Case interviews*

The study used qualitative data gathered through semi-structured interviews conducted with the participants who are industry experts / stakeholders in food industry and having little in-depth knowledge of Blockchain technology or Blockchain experts having food sector awareness. Six semi structured interviews are carried out in the leading technology and food chain companies. The respondents participated in this study are experienced people who are either expert in technology firms with a good awareness in food chain or vice versa or having in knowledge in both. The average experience of the respondents participated in our study is 15 years. Our respondents possess a post graduate degree in terms of education. Basically, a semi structured questionnaire is developed with major twelve questions as shown in Appendix that covers all our open pragmatic questions related to food and Blockchain challenges and opportunities in terms of four categories, namely: technology, people, process and performance.

**Findings**

The analysis of selected literature reveals that the most opportunities to use the Blockchain technology in food sector are to increase transparency throughout food supply chain, accurately track goods, maintain permanent ledger, reduce cost, decentralize infrastructure, improve efficiency, enhance fraud and security, scale ecosystem, automate and innovate. However, in tandem to opportunities there are several impediments to use this technology, they are complex 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 for example, if data can be updated then immutability is lost i.e. if data cannot be updated then how to deal with changes in real world, transaction speed such as throughput, transparency such as transparency in data with stakeholders will maintain business confidentiality, level of transparency, digitalization, training, awareness and too many choices limit the use of this technology.

Based on this review, it is understood that the Blockchain technology could improve the traceability of shipments by providing better access to information and allow food providers to identify the precise point of any contamination before it causes further lost revenue or waste products. Food security lead to low transaction costs and instantaneous application. Unique digital identifiers to food products would make them traceable through supply chains such as products origin, growth conditions, batch numbers, the factory which they come from, the processing methods, expiration dates, temperature during storage and even distribution details.

Among various types it is strongly believed that consortium Blockchain are known as “permissioned blockchains” where the consensus process is controlled by a pre-selected group (owner). Consortium Blockchain brings the like-minded organizations together and enabling a new level of trust and transparency based on a single view of the truth, therefore consortium blockchains are the widely accepted and suited model for use in business. From this aspect further investigation is needed to understand consortium Blockchain technology might be the most suitable supply chain collaboration method in food industry for food track and traceability, which enables a safer, more affordable, 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 2.

Overall from Table 2 it is obvious that opportunities and impediments are plenty in people and technology perspectives. Whereas as expected it is early stage to figure out opportunities and impediments in the performance perspective. Interestingly we didn't see many issues in the process perspective. Measuring food loss, standardization, regulatory and legal acceptance are the immediate opportunities for people to consider in the process perspective of application of Blockchain on food sector. Temperature management, validation and standardization are potential avenues for future researcher to work further.

Quite a lot opportunity exists in the people perspectives out of which redistributing surplus food, increasing customer loyalty, corruption resistance, overall reduction in food price, anti-authoritarian espousing protopian with free decentralized society will make multiple stakeholders to espouse Blockchain in the future. However, if the community as whole can focus on preparing competent manpower, creating a recognized consortium and develop 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 huge impediments since Blockchain as a whole is new to food chain, hence, there are several technical issues that need to be sorted out before it come into existence starting from data capture, network maintenance, enterprise architecture model, interoperability between cold chain and block chain. Among all it is interesting to notice the massive requirement of infrastructure and security will boost the usage of Blockchain widely in the food sector. From the opportunity point of view, it is quite obvious that there are massive benefits considering risk in implementation.

*Table 2 – Blockchain enabled food supply chain opportunities and impediments framework*

| # | Opportunities | Impediments |
|---|---|---|
| Process | • Regulatory and legal acceptance<br>• Standardization<br>• Rewarding and keeping track of food loss. If we have data to analyses where food loss happens, we will have ability to stop or decreased it dramatically | • Freezing temperature management in terms excess standard and market values spoiled milk and meat, salmonella-contaminated cheese, coliform bacteria in food or beverages<br>• Validation and standardization research |
| People | • Redistribution of surplus food<br>• No manipulation, cryptology, reduction of transport, storage, handling cost, time and increase quality<br>• Understand food loss and waste<br>• Customer loyalty, credibility & reduce costs<br>• Traceability and transparency<br>• Corruption resistance, traceability, authenticity, disintermediation, robustness, confidentiality<br>• Better bullwhip effect<br>• Openness culture<br>• anti-authoritarian; espousing protopian dreams of a free and decentralized society | • The skilled personal is required<br>• unique digital identifiers<br>• Standards<br>• Trustworthy consortium.<br>• Additional investment to work with other party<br>• Regulations and customer demand<br>• Validation, standards and regulation<br>• Not technological it is intellectual transformation, takes time |

*Table 3 - Blockchain enabled food supply chain opportunities and impediments framework - continued*

| | | |
|---|---|---|
| Technology | • Risk benefit will favor Blockchain in terms of transparency and traceability<br>• Need based analysis<br>• Database is used as a client server network architecture<br>• Blockchain standalone for specific purpose<br>• ERP complementary.<br>• Enterprise chain infrastructure | • Legal and security integration is not clear<br>• lack of common technology<br>• there is no central administration<br>• interoperability<br>• Reliable data capture system such as 5G technology<br>• Mining pool, consensus protocols and hashing algorithms for the data access layer needs to be arranged<br>• Technological capabilities (bandwidth etc.) are required for interconnections.<br>• An enterprise data architecture model is required<br>• Radio access network, transmission network, IP backbone network are required<br>• For the application layer, both web and mobile applications are required<br>• ICT system needs to establish a link between Blockchain and ERP systems to transfer the data to the inbound systems.<br>• ICT and cold chain should talk to each other.<br>• Customization of ERP in a food chain is difficult, backward and forward lot traceability<br>• Capacity shortages and other difficulties can be tracked and managed timely.<br>• maintaining your Blockchain network<br>• Blockchain implementations mostly done in C++ which is not very friendly programming language for developers<br>• 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. |
| Performanc | • Compliance at micro level delivery time, lot size, storage and transport conditions. | • Performance (latency, speed):<br>• Fresh preservation compliances |

## Conclusion

Blockchain technology in food industry has considerable potential but it needs a substantial academic work, as there are many technical problems and obstacles. The technology transfers more business relationships into code (law). Industry public leaders and should embrace Blockchain as an opportunity and should be added to a digitalization

strategy currently affecting the entire food industry. Stringent regulations at both the national and international level need to be done. Transparency, productivity, competitiveness and sustainability of food industry could be enhanced. The technology will have a major role in food supply system the but right use cases (meat, dairy, fish, fruit, and vegetable products) need to be established. Nonetheless, the research should look at how to generate evidence-based Blockchain solutions to democratize data for the entire food system.,

Our study answered the major research questions such as basic characteristics of Blockchain technology such as decentralized, transparency and immutability, and creation and movement of digital assets, trustless exchange, process integrity, durability, reliability, and longevity will be highly helpful to the food industry. Non-manipulation of data, transparency, security and centralisation will improve collaboration among stakeholders.

Customization of ERP is a big challenge in food chain, as there are different types of products, 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 other challenge. ERP is an expensive solution and it should be customized according the enterprise needs.

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

All parties in Blockchain are responsible to distribute the right information. The retailer can monitor the current capacity of producers and get connected directly to make new orders. In the Blockchain, not only capacities are available, also whole traceable system enables to collect the information like delivery time, lot size, storage and transport conditions.

ICT system needs to establish a link between Blockchain and ERP systems to transfer the data to the inbound systems. For the application layer, both web and mobile applications are required. Mining pool, consensus protocols and hashing algorithms for the data access layer needs to be arranged along with smart contracts and cryptographic signatures.

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**Appendix**

## 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?