A content based literature review on the application of blockchain in food supply chain management

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Abstract

To address food insecurity and achieve efficient food recall, many technologies have been investigated in recent years. One of the most promising technologies is Blockchain, which already been successfully used in financial aspects such as bitcoin, is attracting interests from food supply chain management. As blockchain has characteristics such as decentralization, security, immutability, smart contract, it is therefore expected to improve sustainable food supply chain management and food traceability. This paper uses content analysis methods to carry out a comprehensive systematic literature review in blockchain adoption within food supply chain. We proposed four propositions and five potential challenges.

Keywords: Blockchain, food supply chain

Introduction

Food systems are complex and keep changing over time (Wognum *et al.*, 2011; Yakovleva, 2007). Customers have growing concerns of food security and quality, and an increasing demand of food supply chain transparency. From the food safety survey in 2018, more than two-thirds (68.3%) of participants worry about food fraud problems (Fortune, 2018). According to the World Health Organization (WHO, 2015), almost 1 in 10 people get sick due to foodborne disease each year. Food hazards can cause more than 200 diseases by bacteria, chemical and other contaminations, the foodborne and waterborne diarrhoeal diseases can kill about 2 million people annually including children (WTO 2015). Food crisis ranks the seventh risk in terms of impact by the World Economic Forum in 2018 (WEF, 2018). The most well-known food scandals include Sanlu milk scandal in China (2008), horse meat scandal in the UK (2013), outbreak of E.coli of Romanian lettuces in America (2018) which are only a piece of the food recall iceberg. In 2018, there were 1935 recalls reported, according to US Food and Drug Administration (FDA 2019).

Moreover, globalisation and outsourcing make food system even more complex with more suppliers and companies involved (Christopher *et al.,* 2011; Roth *et al.,* 2007). The longer geographical distance of food supply chain from producers to consumers has also became a challenge to maintain food quality and to achieve fast food recall when necessary. It is not just customers who have doubts, food companies also suffer economic loss from product recalls, which can cost on average $10M for a food company for one recall (Tyco Integrated Security, 2012). Indirect losses and further damages on brand reputation and sales are countless. Within a complex food supply chain, efficient traceability system can make significant contribution in food recall. It can isolate certain products and ingredients from the root of the problem in fast speed to prevent further loss.

Blockchain, as a decentralized platform that not only allows peer to peer direct transaction, eliminates middlemen, but also validate information by cryptography and records history permanently has drawn a lot of attentions, is believed to be a compromising solution to impove traceability and revolutionise the modern food supply chain (Kouhizadeh and Sarkis, 2018). The primary aim of this paper is to investigate how blockchain has been used in the food supply chain area, and how this technology can help to address food security issues. This paper applies a literature review method and expects to answer the following research questions:

Question 1: What are the researches have been carried out upon blockchain’s adoption in food supply chain management (FSCM)?

Question 2: What benefits can blockchain bring to the FSC?

Question 3: What are the challenges of blockchain’s adoption in FSC?

Previous researches have introduced a few integrations of blockchain and FSC, with the application of Internet of things (IoT) (Tian, 2016; 2017), by applying case studies (Verhoeven *et al.,* 2018), or Survey (Hackius and Petersen, 2017). The studies presented both benefits and challenge of blockchain adoption. However, no literature review has been carried to explore this topic in a systematic manner. Therefore, this paper is trying to fill the gaps, by collecting and summarising related papers, and giving a deeper analysis of the literatures to answer the questions mentioned above. The structure of the following chapters is as follows: the second chapter is a literature review on the background of the key concepts, third chapter is the research methodology and review processes, the propositions and discussions are in the fourth and fifth chapter, while the final chapter is the conclusion to summarize the whole research.

Literature review

Food supply chain

Food supply chain is defined by Folkerts and Koehorse (1997, p. 11) as “a set of interdependent companies that work closely together to manage the flow of goods and services along the value-added chain of agricultural and food products, in order to realize superior customer value at the lowest possible costs”. Compare to the other industries, food products have more vulnerable value chain, and require more attention over handling processes (Aung and Chang, 2014; Ting *et al.,* 2014; Yu *et al.,* 2013). The natural feature of changing quality all the time make keep food safety and quality a challenge (Aung and Chang, 2014). Outer environments such as temperature and transports can also contribute to affect products quality and freshness. Besides, complex food supply chain also means higher risks of products failure, which includes food borne disease, food poisoning, low quality food, counterfeit products, or mislabelling and undeclared ingredients after producing (Lin *et al.,* 2018; Ting *et al.,* 2014; Tyco Integrated Security, 2012). Food security is a shared responsibility in a supply chain, and requires efficiency and closer partner collaboration to maintain the value chain and eliminate products failure.

Modern centralized food supply chain heavily relies on the central powers to control information flow, which can be the threats to the transparency, information equality and trusts (Tian, 2016; Tian, 2017). Lack of transparency can lead to certain risks include: information inequality between stakeholder (Mao *et al.*, 2018), bribery (Tian, 2017), information fraud, etc. Therefore, a single failure can lead to the disruption of the whole supply chain (Tian, 2017). For certain products, such as organic, kosher, vegan or fair trade products, it is even harder for consumers to know the products and information authenticity. Even laws and authority verifications have been helpful, deep concerning and lack of trust of food industry and food quality still remind.

Blockchain

The concept of the decentralized peer to peer ledger was introduced by Nakamoto in 2008. It has been successfully applied in financial area such as Bitcoin, and it triggers huge interests in multiple areas including, supply chain, property, voting, etc. The fundamental technology of blockchain has a few main features: decentralization, immutability, security and smart contract.

- Decentralization

Decentralization eliminates the central powers and address information inequality by allowing direct transaction between users. Users have equal power to examine transactions, to keep copies of records and to access entire transaction history. In food supply chain, from the raw material suppliers to customers, products information can be recorded along the whole supply chain and ready to be retrieved upon on demand. For example, the end users, consumers, can obtain the detailed information on the products include authenticity and origins, etc. Producers can also monitor their suppliers to make sure raw material quality meet requirements. Therefore, decentralised supply chain can eliminate information inequality and build trust.

- Security

Data security can be achieved by blockchain consensus algorithm. Transactions are examined by users to define computer calculations. When decentralization eliminates central power on the network, it also prevents a supply chain breakdown because of a single point failure will not lead to the failure of the whole network, which can reduce the chance of hacking. Technically, hacking can only be achieved when the majority (at least 51%) of users are taken over, which will take a considerable amount of energy/time. Therefore, the more complicated blockchain network with more users, the more difficult for the hacking behaviour to happen. When applying into food supply chain, blockchain can keep records and data safe, and eliminates the risks of hacking and data stealing.

- Immutability

Blockchain ensures the records are original and authentic by its immutability feature. This means history data cannot be altered without warning other users, which can prevent the human intervention on records. This feature makes blockchain as a powerful proof to investigate for accountabilities under food crisis and food recall. It can prevent any stakeholders change history and escape from responsibilities. It is also an evidence for ensuring producing process especially for products such as organic, halal, fair trade, etc., immutable records can provide customers buying confidence. However, immutability cannot always guarantee the raw information authenticity, it can be considered as a strategic tool to encourage stakeholders to take responsibilities for their information.

- Smart contract

Smart contract is a digitalized program which operates automatically when certain agreements are met. The use of smart contact can significantly speed up transactions and enhance trust, save time and labour. For example, in 2014, Maersk have found that over 30 people and organizations have got involved when shipping a container of roses and avocado from Kenya to Netherlands (Park, 2018). It also took 34 days include 10 documents processing days to finish a whole shipping activity, which is also not include missing paper caused delay and time extension (Park, 2018). As the smart contract based on the agreement of all partners, therefore, no single user can make changes. In another word, it can replace "the letter of credit" and protect the partnerships. For instance, the payment can be sent to producers automatically once the products arrived to warehouse.

Traceability

Traceability has many definitions so far, the earliest definition was by International Organization for standardization (ISO 8402, 1994): "the ability to trace the history, application or location of an entity by means of recorded identifications". More precisely, "food traceability is part of logistics management that capture, store, and transmit adequate information about a food, feed, food-producing is correct animal or substance at all stages in the food supply chain so that the product can be checked for safety and quality control, traced upward, and tracked downward at any time required. (Bosona and Gebresenbet, 2013, p.35)".

From the definition, record-keeping is an important element for building good traceability. It not only allows companies to have a clearer view of the supply chain, make better decisions and avoid potential quality risks by providing precise records; but also gives the ability of tracing backward and tracking forward along the supply chain during food recall, which can improve the speed of isolating and finding certain products from certain suppliers (UN global Compact, 2014). For sustainability purpose, traceability is also a way to monitor environmental impacts, therefore, encourage companies to be more sustainable. By demonstrating the resources and products flow, customers have better knowledge and trust on the buying products. Traceability can be the added value to the food products, and be used as a marketing tool to attract more customers and enhance customer trusts. (Dabbene *et al.,* 2014; Golan *et al.,* 2004). The record keeping can also be used as a strategic tool to encourage suppliers to provide quality products (Aung and Chang, 2014; Golan *et al.,* 2004).

Traditional traceability system largely relies on paper-based system or internal computer system, which can be time consuming and incapable for other stakeholders (Aung and Chang, 2014). Traceability can also differentiate companies from success and failure during food recall by accelerating recalls and saving unnecessary costs (Golan *et al.*, 2004). FDA reports that it can take averagely 57 days for a recall, or even up to 10 months sometimes (Mccallister, 2017; O'Donnell, 2017). The slow products recall can lead to deep concerning of food safety and damage company brand image. Technologies include Radio Frequency Identification (RFID), barcodes, smart tags, Wireless Sensor Network (WSN) and DNA based techniques, can provide more efficiency but can be expensive.

Blockchain is considered as a compromising solution to achieve efficient traceability. The early research by Tian (2016) proposed a conceptual framework which integrates blockchain and IoT, and suggested the benefits, include improving efficiency and transparency. There are also many pilot studies that provide the practical implication. The real world pilot study was carried by Walmart tracing mangoes (Yiannas, 2017). Compare with traditional traceability system, mango tracing time reduced from nearly seven days to 2.2 seconds by using blockchain.

Methodology

In order to answer the research questions, this research adopts a literature review method. There are several review papers on blockchain and SCM, however, none of them have a specific focus on food supply chain (Wamba *et al.,* 2018; Wang *et al.,* 2018). These papers provide the foundation of this research. Fink (2005, p3) defined literature review as "a systematic, explicit, and reproducible design for identifying, evaluating, and interpreting the existing body of recorded documents". This paper adopts a content based literature review on the application of blockchain in FSCM. This paper not only thoroughly reviews blockchain, but also considers some practical applications, and aims to provide a more precise and integrated understanding of blockchain and its influences.

This literature review applies six-stage refinement process suggested by Durach et al. (2017): define research question, set inclusion and exclusion criteria, determine searching databases, apply criteria, synthesize relevant literatures, and report findings. Research questions have been provided in the introduction. Therefore, research keywords are blockchain and the food supply chain. Web of science, Scopus and Ebsco are the three online bases that applied for relevant academic literature searching, as the three databases have a wide range of resources, and have been used extensively in SCM research. Peer-reviewed journal articles are seen as a way of high quality communication between research fellows. However, in this paper, due to the early stage of blockchain and the limited published articles, other resources such as conference papers, grey papers, consulting reports, third party reports that can provide more updated information are also considered. The initial search came out 57 results in the three databases.

Removing the duplicated papers and applying inclusion & exclusion criteria (Table 1), the number of useful papers reduced to 23 in the final process (Diagram 1). The final 23 papers are categorized and evaluated by content analysis method (Table 2), which is a systematic and objective research method that been used to quantify phenomena, documents or communications (Seuring and Gold, 2012).

Table 1: Inclusion/Exclusion Criteria

Inclusion	Exclusion
Published in English language	Published in other languages
Papers focus on food supply chain only	Papers focus on any industry rather than food supply chain industry
Published since 2008 to present	Published before 2008
Papers focus on blockchain	Papers focus on other technologies
Peer review/ conference papers, and grey articles	Business news
Management focus	Technique focus

Descriptive analysis is the first insight into all the papers, and suppose to provide a basic view of the selected papers. Among the selected papers, due to the young age of technology, the earliest paper (1 out of 23) was released in 2016, and eight papers in 2017, and the 14 papers were 2018 and onwards. The time trend shows that blockchain tends to gain an increasing research interests in food supply chain area. This also explains well that 13 out of 23 papers are technology and innovation related conference papers. Papers are focusing on different aspect of food supply chain, however 12 out of 23 of the papers focusing mainly on traceability. Papers mainly adopted conceptual framework (13 out of 23), and pilot cases (6 out of 23), three theories (3 out of 23) and survey (1 out of 23) respectively.

Table 2: List of papers by content analysis

Categories	Papers	Tian (2016)	Faye (2017)	Ge et al (2017)	Hackius and Petersen (2017)	Kumar and Lyengar	Lin et al (2017)	Tieman and Darun (2017)	Tian (2017)	Tse et al(2017)	Caro et al (2018)	Hua et al (2018)	Galvez et al (2018)	Kshetri (2018)	Leong et al(2018)	Lin et al (2018)	Perboli et al (2018)	Rejeb (2018)	Tan et al (2018)	Tripoli and Schmidhuber (2018)	Vara et al (2018)	Verhoeven et al(2018)	Yiannas (2018)	Pearson et al (2019)
Focusing area	Food traceability	✓	✓				✓		✓		✓	✓	✓		✓	✓			✓				✓	✓
	Blockchain adoption			✓						✓												✓		
	SCM				✓	✓		✓						✓			✓	✓			✓			
Benefits	Transparency	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
	Information authenticity	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
	IoT management	✓	✓		✓	✓	✓		✓		✓		✓	✓	✓	✓		✓		✓				
	efficiency	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Challenges	Lack of understanding			✓	✓								✓		✓				✓	✓		✓		
	Immature technology			✓					✓	✓		✓		✓			✓			✓				✓
	Stakeholder cooperation			✓										✓	✓		✓			✓				✓
	Trade secrets			✓			✓					✓		✓	✓	✓				✓				✓
	Raw data authenticity			✓			✓							✓		✓								

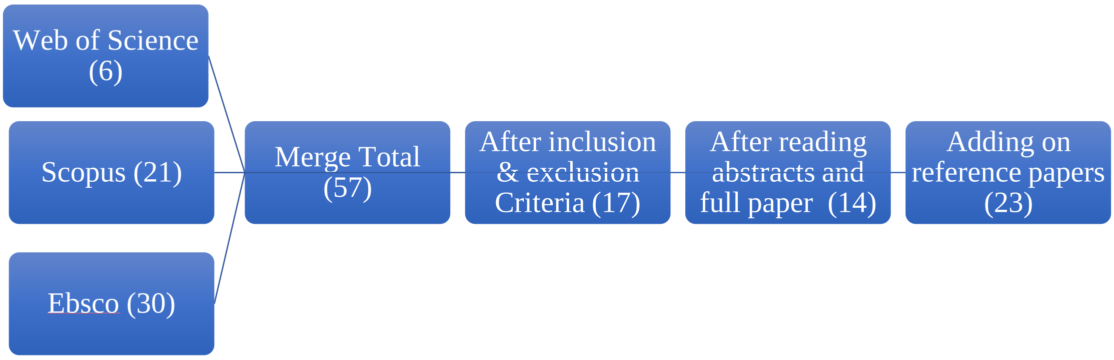

Diagram 1: Paper selection process

Finding and discussion

Blockchain is believed can address the inefficiency in current traceability and enhance trust during food recall (Yiannas, 2017). Galvez et al (2018) suggested that blockchain is a powerful tool to avoid food fraud and to improve traceability efficiency includes time and costs saving, risks reducing, and increasing trust. Similarly, Caro et al (2018) agreed the ability of blockchain on providing transparency and auditability by built blockchain traceability systems. A pilot study of blockchain based mango tracing system was launched in 2016 by Walmart and IBM. By current traceability system, it took almost 7 days to collect all the information of mango movements, and required every stakeholder to contact with each other to get to know the required details (Yiannas, 2017). By blockchain, the time to contact and wait for response from other stakeholders can be eliminated. The movements of mangoes are recorded by each stakeholder along the supply chain, and ready to be checked anytime. The trace time reduced from nearly 7 days to 2.2 seconds by blockchain (Yiannas, 2017).

- Proposition 1: Blockchain can positively improve food traceability

In the centralised supply chain, leading companies tend to choose selected information to open up to the public, which can cause the lack of transparency and trust issues within a supply chain, especially for certain products such as Halal, organic, etc (Tieman and Darun, 2017). Besides of companies themselves, even authorities can contribute to cover up unlawful hazards. For example, the China Sanlu milk scandal did not get exposed on the first place due to the cover up by company managers and local authorities (Barboza, 2008). Information credibility is questioned in centralized food supply chain (Hua *et al.*, 2018). Blockchain, as a decentralized platform, allows authorised users have equal powers to have a copy of history and access it directly without central power intervention, which can prevent any large powers over the information flow and provide transparency along the supply chain, may be the solution for information inequality.

Information fraud is another major concern within centralized supply chain, where transparency and visibility remain low. Companies can erase or change history to escape from taking responsibilities or hiding the truth (Biswas *et al.*, 2017; Caro *et al.*, 2018; Tian, 2016; Tian, 2017). By blockchain, once transactions are validated and are added on the blockchain, the original records stay permanent and can be retrieved anytime (Tian, 2017). In 2016, Walmart and Tsinghua University traced pork in China from-farm-to-fork. The finding shows that blockchain can improve information authenticity, reduce information errors and gain trust (Yiannas, 2017). This pilot case suggested that the digitalization of records and documents not only can save time from manual paper check, but also eliminate risks from information fraud.

- Proposition 2: Blockchain can address food supply chain information asymmetry and information fraud

Many studies have combined blockchain technology with IoT, and suggested that blockchain can help to manage IoT and make supply chain more efficient (Galvez *et al.*, 2018; Leong *et al.*, 2018; Lin, *et al.*, 2018; Tian, 2016;2017). IoT such as RFID, WSN, connects objects and provides intelligent, reliable and high speed information exchange. Information such as temperature and humidity can be captured automatically by IoT sensors in near real-time, which is significantly important for food products, as the quality is closely related to the external environment (Lin *et al.*, 2017;Tian, 2016). The automation by IoT can increase the efficiency of monitoring and reduce human intervention and errors (Lin *et al.*, 2018; Tian, 2016; 2017). By combining with smart contract, once anything goes wrong such as losing temperature control, the digitalized program can be triggered automatically and send register users warnings, which can prevent further damage (Caro *et al.*, 2018; Lin *et al.*, 2017; Tian, 2017). There are a few blockchain pilot studies that have incorporation with IoT, such as WWF using smart tagging combine blockchain to prevent illegal tuna fishing in Fiji; Belagricola uses IoT and smart contact to track grains and ensure the quality (Leong *et al.*, 2018).

- Proposition 3: blockchain can positively integrate with the IoT management in a food supply chain

By using blockchain, food supply chain is found to be more sustainable by efficient products management and fast food recall. When products information is updated on blockchain in near real-time basis, stakeholders can have the awareness of products situation immediately. For instance, Walmart realized that fresh products such as mangoes can wait to be checked up to four days in the boarder (Yiannas, 2017). In this case, Walmart can accelerate the products checking process and give mangoes more shelf lives. The improvement of information transparency can improve the supply chain efficiency and eliminate unnecessary products wastes. Depends on the information, companies can make more accurate customer demand forecasting based on the point of sales data (Wang *et al.*, 2019).

- Proposition 4: blockchain can reduce food wastes

The references also suggest following challenges:

Lack of deep understanding of the blockchain technology

Public still has not enough knowledge of blockchain, even many people working within the SCM area still having troubles to fully understand about blockchain potentials (Hackius and Petersen, 2017; Galvez *et al.*, 2018). Verhoeven et al (2018) suggested that many companies tended to choose blockchain as a solution before diagnosing company issues, which show a lack of deep understanding of blockchain true potentials. For instance, Verhoeven et al (2018) suggested that in Walmart's pilot study of tracing mangoes, the tracing speed increase by blockchain should due to the eliminating of manual validation process rather than change to an efficient platform. Leong et al (2018) also suggested that different stages of the supply chain might have different requirements on technology adoption.

Technology scalability issue

The second challenge is called the "scalability trilemma" by the founder of the smart contract platform Ethereum -- Vitalik Buterin (Perboli *et al.*, 2018). It is hard to achieve decentralization, scalability and security at the same time, only two out of three can be achieved at one time (Ometoruwa, 2018; Perboli *et al.*, 2018). Scalability determines how large the capacity the network can be. Currently, Ethereum can process 15 transactions per second, while other platform such as Visa can process 45,000 transactions per second (Coindesk, 2019). Mining process can ensure high degree of decentralization and security; it can also cause slow speed of validations when a large number of transactions are happening. For vast global food supply chain, the scale can reach about Petabyte per year by assumption (Pearson et al, 2019). Pearson et al (2019) assumed that blockchain is more likely to happen in niche areas in a food supply chain, where the blockchain potentials are necessarily needed. Different stages of the food supply chain may have different requirements for blockchain adoption (Leong et al, 2018)

Raw data manipulation before uploading to blockchain

Although, blockchain can provide a robust way to keep records, many studies have concerned about raw data manipulation, for example by tempering with IoT sensors (Galvez *et al.,* 2018; Lin *et al.,* 2017). It is also possible to make damages on products without notifying blockchain users (Kshetri, 2018). In this case, third parties such as governments and certifications can get involved by making regular checks to ensure raw data authenticity (Tian, 2017; Leong *et al.,* 2018). Meanwhile, the immutable recording can also encourage stakeholders to take responsibilities for their products and information.

It is hard to require all stakeholders within a food supply chain to adopt blockchain

It is difficult for all stakeholders get involved due to the different levels of knowledge and infrastructures. The implementing and infrastructure mentioning fee can also be the barriers (Leong *et al.,* 2018; Pearson *et al.,* 2019; Perboli *et al.,* 2018). Perboli et al (2018) suggested that the implementing fee of blockchain can be highly sustainable and can be paid back by saving on the costs. They also suggested that replacing the system partially by blockchain is more reasonable. It is also important for developers to make blockchain easy to use and to deploy with low initial costs (Leong *et al.,* 2018; Pearson *et al.,* 2019).

Regulations/laws need to be updated

By examining the external environment factors for blockchain implementation, Tse et al (2017) suggested that third parties also gain benefits from blockchain. Many countries and authorities have showed their interests and supports (Tse *et al.,* 2017): China has published Blockchain White book and launched blockchain related projects (Tse *et al.,* 2017); ISO Blockchain (TC307) was also working on developing a global blockchain standards (Pearson *et al.,* 2019). However, there is no strict blockchain policy in food supply chain area so far. As Leong et al (2018) and Pearson et al (2019) suggested that policies and rules need to be developed to protect users and company secrets. It is a challenge to invite all stakeholders on board before some completed policies and rules are being launched.

Contributions and limitations

This paper, to our knowledge, is the first to investigate how blockchain engage into food supply chain specifically. The paper provides a fundamental and comprehensive understanding of blockchain and its potential impacts, which will not only can be a useful guide for new researcher in relevant area, but also can provide some deep insights for practitioners such as company decision-makers. By identifying and analysing the most related papers, this work lays a solid ground for future research on this area, and points out some research directions. This paper also gives technology adopters a better understanding of blockchain, and explains them some possible adoption challenges and reminds them to use blockchain fit right into the issues.

Despite from the contributions, the author also would like to point out some limitation and future research areas. First of all, due to the immaturity of the technology, the paper is based on very limited number of theory-based researches with several pilot case studies, which may lead to research bias. The big success of Bitcoin may cause a "hype" of blockchain and potentially lead to positive perspectives. In this case, the future research can focus on blockchain implementation in the real world and provide more empirical evidence. Secondly, food supply chain is complicated and various. This paper bases on the food supply chain in general, which can remind the future research to focus on specific food products and present more precise findings.

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