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Blockchain technology in the food supply chain: influences on supplier relationships and outcomes

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Abstract

Increasingly, as the US food supply chain has grown in complexity, the corresponding challenges of managing the network of manufacturers, distributors, and retailers, while ensuring supplier relationships, food safety and reducing food fraud have become paramount. Blockchain technology, which possesses the characteristics of immutability and decentralization, offers immense benefits in the food supply chain. Drawing on affordance theory and blockchain literature, we build a research model of the affordances offered by blockchain namely traceability, visibility and validity, and its influences on the positive supplier outcomes in the food supply chain. We validate our model using exemplar cases of the IBM and Walmart blockchain, and the Nestlé corporation's use of blockchain technology, and the corresponding supplier relationship benefits derived from them. This study has important implications for research and practice as it offers a nuanced affordance perspective to study and apply blockchain in the food supply chain.

Keywords: blockchain, food supply chain, immutability, decentralization, traceability, visibility, validity

Introduction

The food supply chain in the US, which encompasses production, processing, distribution and retail activities, is built on an intricate and complex network of manufacturers, distributors and retailers (NIH, 2017). Although regulated to ensure efficient, reliable, and safe delivery of food, the US has witnessed major food safety events in recent years. Practitioner reports state that between 2009 and 2018, STEC bacteria were the cause of 40 outbreaks, 1212 illnesses, 77 cases of hemolytic uremic syndrome, and eight deaths in the US and Canada (Marshall et al., 2020; Waltenburg et al., 2022). The 2018 E-coli outbreak alone impacted 36 states in the US, causing 210 illnesses, 96 hospital admissions, and five fatalities (CDC, 2019). Notably, it may take days to several weeks to pinpoint the origin of the outbreak, making it extremely problematic in today's increasingly interconnected world. Therefore, innovative technology such as blockchain can help address these challenges in the food supply chain, and become an important imperative for food retailers, distributors, and manufacturers.

Prior literature illustrates the characteristics of blockchain technology to maintain an immutable and decentralized record of every transaction in the food supply chain. Blockchain makes it easier to trace the origin of products and any intermediaries or processes involved (Hendershott et al., 2021). Suppliers can

track product movement in real-time, which can help quickly identify the source of any issues or delays. Blockchain can help identify and isolate the source of foodborne illnesses by tracing the movement of contaminated products in the supply chain, reducing the spread of illnesses and the number of people affected (Behnke & Janssen, 2020). Blockchain therefore provides much-needed traceability, visibility, and validity of data, offering the opportunity for improved food safety, better supply chain management, and reduction in food fraud.

In this study, we draw upon affordance theory (Gibson, 1977), and its applications in Information Systems (IS) (Markus & Silver, 2008; Volkoff & Strong, 2013; Zammuto et al., 2007) and extant research in blockchain technology to illustrate influences of affordances of blockchain and its influence on supplier relationships in the food supply chain. Specifically, this research contributes to the current blockchain literature by applying the affordance theory to the use of blockchain technology using two exemplar cases of IBM-Walmart collaboration and Nestlé corporation's use of blockchain. Through these applications, we highlight how the affordances of blockchain technology are being utilized to improve supplier relationships in terms of food safety, supply chain management, and reduction in food fraud. The research questions this study seeks to address are as follows:

1. *What are the affordances of blockchain technology in the food supply chain?*
2. *What are the influences of the affordances of blockchain technology on supplier relationships and outcomes in the food supply chain?*

The rest of this paper is organized as follows. The research background and framework sections discuss affordance theory, and literature on food supply chain and blockchain technology. Next, we illustrate IBM and Walmart's food supply chain network and the Nestlé corporation as exemplar cases for using blockchain. We detail the affordances blockchain technology provides and its influences on supplier relationships. We conclude by discussing the implications for researchers and practitioners from our study.

Research Background

The US Food supply chain faces various issues, including concerns about food safety, lack of visibility, waste, and fraudulent products. These problems can occur at various points in the supply chain, from production to retail, and have significant economic, environmental, and social impacts. For instance, according to the USDA, 30 to 40 percent of the food produced in the United States is wasted, resulting in financial losses and environmental degradation (USDA, 2023). Additionally, food fraud is an exigent international concern, with counterfeit products often entering the supply chain through mislabeling, adulteration, and substitution of ingredients (Brooks et al., 2021; Ehmke et al., 2019).

Traceability is critical to food safety, central to supplier relationships and global food trade (Pearson et al., 2019). According to Aung and Chang (2014), traceability systems that include identifying units/batches of all ingredients, products, product movement and transformation information, and a system linking these data are essential in food supply chains. In addition, the ability to trace food items within and along a supply chain is legally required. The complex and diverse nature of food supply chains often makes tracking the origin and journey of food items from farm to table challenging.

This lack of visibility can lead to food safety issues, fraud, and mislabeling. The Centers for Disease Control and Prevention (CDC) estimates that foodborne illnesses result in 48 million illnesses, 128,000 hospitalizations, and 3,000 deaths annually in the United States (Marshall et al., 2020). The complexity of supply chains can make it difficult to quickly identify and contain outbreaks, as demonstrated by the 2018

E. coli outbreak. Furthermore, when multiple parties are involved in the supply chain, and records are kept on paper, the process can be slow and inefficient, leading to delays, inflated costs, and other failures. To address these food supply chain issues, in this study, we draw upon affordance theory to discuss the various affordances offered by blockchain technology in the food supply chain, and its influences on supplier relationships.

Affordance Theory

Affordance theory, proposed by Gibson (1977), suggests that the environment provides various opportunities or "affordances" based on its perceptible properties or usefulness (Gibson, 1977). Several researchers in IS have elaborated on the application of affordance theory in the domain of information systems, its adoption and use (Markus and Silver, 2008; Zammuto et al. 2007). The theory posits that information systems provide certain positive affordances, enabling the user to use them appropriately to achieve benefits. For example, a smartphone provides positive affordances such as the ability to use various apps, which enables the user to make phone calls, take photos, send, and receive text messages, do audio/video calls etc.

Applying affordance theory to Blockchain technology, we contend that blockchain offers unique capabilities in the food supply chain. Stakeholders can securely record and track every stage of the food supply chain by utilizing blockchain's immutable and decentralized nature (Hendershott et al., 2021), thereby reducing fraud, ensuring food safety, and facilitating effective supply chain management. By facilitating enhanced accountability throughout the entire supply chain, real-time product tracking, and improved quality control, this visibility has the potential to revolutionize the food industry.

Research Framework: Blockchain Technology and Affordances

Figure 1 provides the research model for this study. We postulate that the two blockchain characteristics of immutability and decentralization influence the blockchain affordances of traceability, visibility, and validity. Blockchain technology can be considered a distributed ledger with four key characteristics namely decentralization, cryptography, consensus, and immutability that set it apart from centralized ledgers (Chong et al., 2019). Of these key blockchain characteristics, immutability and decentralization are important in the food supply chain and provide the key affordances. Further, we postulate that these affordances influence food supply chain outcomes of efficiency, food safety improvements and food fraud reduction.

The immutable nature of blockchain means that records stored on the chain are difficult or impossible to change (Lansiti & Lakhani, 2017). If a record is altered, the corresponding hashes in the surrounding blocks no longer match, and the error is immediately evident (Pilkington, 2016). Blockchain copies are stored on multiple nodes or servers to decentralize the data (Andersen & Bogusz, 2019). Most nodes must agree (come to a consensus), and minority copies with variant records are removed from the decentralized network. Ensuring that changes to the records require corresponding changes to most duplicated nodes, making it difficult or impossible to alter validated transactions. The inventory is scanned in these touchpoints as food material is harvested, picked up at the farm, transported to a distribution center, and delivered to a grocery store. This event log is stored in a decentralized blockchain in real time providing a complete history. This history now includes a detailed record of the food material, and all the touchpoints made along the way including everyone or everything that encountered it.

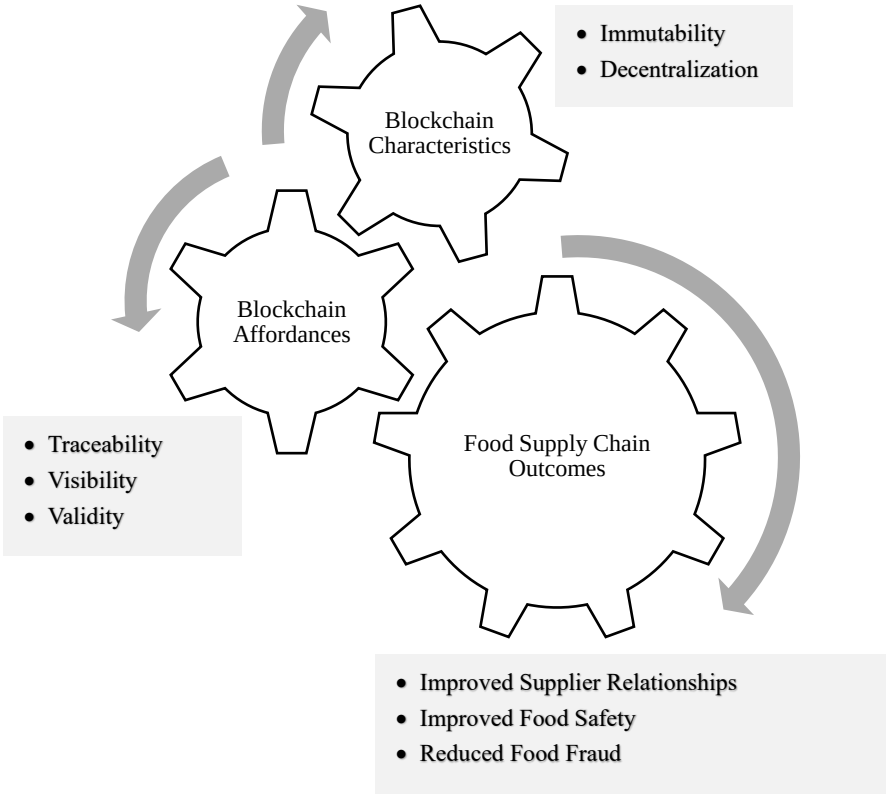

Figure 1: The Influence of Blockchain Affordances on Food Supply Chain Outcomes

The immutability and decentralization characteristics of blockchain technology ensure the integrity of records throughout their lifecycle (Lansiti & Lakhani, 2017). By establishing an audit trail, blockchain enables comprehensive traceability of food history and offers visibility and validity. Empirical evidence from case studies, real-world implementations, and systems design has consistently demonstrate that blockchain enhances traceability, visibility, and validity within the food supply chain. For instance, in high-end wine authentication, blockchain-enabled tags have been employed to provide visibility to consumers, enabling them to track the product's journey from the vineyard to the retail store (Rogerson & Parry, 2020).

Similarly, a systems design project focused on beef exports from Australia to China utilized blockchain and IoT to establish the validity of the supply chain, leveraging the consensus mechanism to create a shared body of knowledge (Powell et al., 2022). Furthermore, practical use cases have showcased the traceability aspect of blockchain technology.

Notably, the AgriBlockIoT project developed a decentralized traceability system for the Chinese food market, incorporating two blockchain implementations and adhering to Hazard Analysis and Critical Control Points (HACCP) principles to ensure food safety (Caro et al., 2018). Thus, in the context of the food supply chain, the affordances of traceability, visibility, and validity can be attributed to the blockchain's immutable nature and decentralized characteristics (Rossi et al., 2019).

Blockchain Exemplars

The IBM-Walmart Blockchain

Walmart, a global leader in retail in the US and global markets, has a large footprint in the food supply chain ranking as the top US grocery retailer with 25.6% market share last year (Guzman, 2023). Walmart's grocery sales constituted 58% of its overall net sales in the US (Ozbun, 2023), signifying the importance the food supply chain plays in its business. Walmart has clear sustainability goals as part of its corporate strategy as explained by the Executive Vice President and Chief Sustainability Officer (Walmart, 2023) :

> *"We must all take urgent, sustained action to reverse nature loss and emissions before we reach a tipping point from which we will not recover. People have pushed past the earth's natural limits. Healthy societies, resilient economies and thriving businesses rely on nature.*
>
> *Our vision at Walmart is to help transform food and product supply chains to be regenerative, working in harmony with nature - to protect, restore and sustainably use our natural resources."*

To meet its sustainability goals, Walmart invests in sustainable practices throughout the world including in *"... regenerative agricultural practices"* and *"... place-based efforts to preserve natural ecosystems"* (Walmart, 2023). Tied in with these global efforts, Walmart's goals also align well with seeking to improve efficiency, maintain food safety, and reduce food wastage and fraud in the food supply chain.

Blockchain Affordances and its Influences on Supplier Relationships

Blockchain can offer several key affordances which enhance supplier relationships: Traceability, Visibility and Validity. Over the years, IBM's blockchain technology has gained a growing reputation as one of the premier blockchain technologies in the world. Figure 2 shows the timeline where Walmart partnered with IBM and Hyperledger Inc. in 2016 to start a blockchain initiative to improve food traceability, efficiency and safety (Kamath, 2018). We illustrate the affordances of this blockchain technology through Walmart's use of the blockchain on several food materials including mangoes, pork, and seafood.

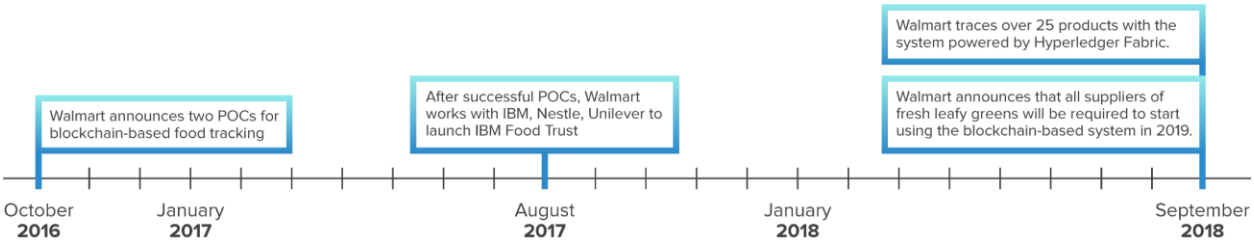

Figure2: Timeline of Walmart and IBM/Hyperledger, Inc blockchain initiative (Source: Hyperledger, 2023)

Traceability

Walmart's first initiative was to create pilot programs to study the feasibility of the blockchain system in the food supply chain (Kamath, 2018). This food traceability pilot program was created with IBM, with Hyperledger Inc., an open-sourced blockchain platform being the backbone of blockchain technology. The first pilot was to trace mangoes sold in the US. While it took several days to trace the mangoes to the source using the traditional system, it took merely 2.2 seconds using the food traceability system (Sristy, 2021).

The first pilot was followed by the second initiative, with a Walmart, IBM, JD and Tsinghua University in Beijing partnership to implement a Blockchain system to trace pork for its Chinese supply chain (Aitken, 2017; Kamath, 2018). With one of the outcomes of the partnership being to establish standards and norms for the food supply chain in China, the participation of an academic university like Tsinghua University was to build research focus in the food supply chain initiative. These initiatives were remarkable for Walmart, considering the sustainability goals it had set out to accomplish. Further, this initiative also helped Walmart to build stronger relationships with suppliers and manufacturers in China, while ensuring food safety and sustainability.

Visibility

Walmart's next initiative was to create a "Food Trust Network" (IBM Food Trust) formed with several major food companies such as Dole, Nestlé, Tyson Foods, and Unilever, to collaborate on developing new applications. Two key examples from Walmart's application are provided below which explains the blockchain visibility perspective. As explained earlier, an important aspect of blockchain technology is the ability to decentralize data capture i.e., capture at the source, which was essential in ensuring visibility in the food supply chain.

In 2019, Walmart introduced Blockchain system for the end-to-end traceability of shrimp sourced in Andhra Pradesh, India, and shipped to select Sam's Club locations in the USA (Mathur, 2019). The Sam's Club example has the potential to ensure that the shrimp sourced from the community were from sustainable sources, improve supplier relationships, and adherence to food safety standards such as the Best Aquaculture Practice (BAP) (Mathur, 2019). Walmart Canada partnered with Bison Transport in 2019 and developed DL Freight network using Blockchain technology to manage invoice and payment processes (Vitasek et al., 2022). Besides significantly reducing discrepancies in invoices and disputes, the system helped improve relationships between partners in their supply chain. Further, the study reports that there were also operational improvements such as optimizing efficiency, time, and safety in transportation.

Validity

One of the key characteristics of Blockchain technology is its ability to have decentralized immutable records. This means that every change in the record ledger is logged, ensuring data validity. Food supply chain participants must record data about product origin, batch numbers, processing details, transportation information, and other details at various stages (Sristy, 2021). The key difference between the traditional means of storing information in siloed systems and the blockchain is that the blockchain system is a shared ledger. A shared ledger means that data, once stored in the blockchain, cannot be unilaterally changed (Pilkington, 2016) by any one manufacturer, distributor, or supplier.

Several examples from Walmart's application of blockchain in the food supply chain, such as the pilot with Mangoes, Pork and shrimp, lend credence to the importance of data validity in the blockchain (Aitken, 2017; Kamath, 2018; Mathur, 2019). Information stored on the blockchain accurately records various stages

of the food product's journey. Through the sharing of data in the food trust collaborations, Walmart was able to provide visibility and validity throughout this supply chain to all its partners in the network. This level of transparency has the potential to enable supply chain efficiencies and stronger supply chain relationships leading to food safety and reduction in food fraud.

Nestlé Corporation

Established over 150 years ago with headquarters in Switzerland, Nestlé is an industry-leading global foods company with a market capitalization of over $ 350 B in 2023. Nestlé's product portfolio includes over 2000 brands and believes in the slogan "Good Food Good Life". Its popular product categories include baby food, water, cereals, chocolate and confectionery, coffee, dairy and other food categories. Nestlé is committed to sustainability goals, reducing environmental impacts, improving communities, and providing safe foods to create a *stronger* company, positive impact and value for shareholders and stakeholders.

> *"Nestlé was one of the first companies to make a commitment to deforestation-free supply chains. At the time we knew it would be challenging, but we felt it was a moral imperative - for our environment, for the people, and for our planet at large."*
>
> - *Magdi Batato, Executive VP and Head of Operations*

Nestlé sets internal goals regarding the company's positive impact on the environment and the communities where it sources ingredients and sells its products. For example, Nestlé is committed to a deforestation-free supply chain for its cocoa supply by 2025 (Nestlé, 2023a). The company is an industry leader in goal progress visibility and makes a wealth of data on its sustainability programs available to the public.

Blockchain Affordances and its Influences on Supplier Relationships

Nestlé's initial foray into using blockchain in the food supply chain began in 2016 when it was part of the Food Trust blockchain initiative established by IBM and Walmart. Later in 2019, Nestlé formed a partnership with OpenSC, an open source blockchain platform for tracking food materials in its food supply chain. We illustrate the affordances of this blockchain technology through Nestlé's use of the blockchain on several food materials including palm oil, dairy and coffee. The use of blockchain technology at Nestlé in these processes has enabled key affordances, resulting in direct influence on improved supplier relationships.

Traceability

Maintaining certified traceability of food products is a key motivation for utilizing blockchain technology at Nestlé. Nestlé participated in the IBM Food Trust blockchain technology platform for some food products in its first initiative. Through the blockchain initiative, Nestlé was able to track end-to-end palm oil production, which suffers from deforestation issues, ensuring that the suppliers adhered to 100% sustainability practices (Nestlé, 2023b). Blockchain technology was used to trace dairy products through the supply chain from New Zealand where the milk is produced, to the Middle East where the dairy is processed and distributed in Nestlé factories and warehouses (Nestlé, 2019).

Nestlé used blockchain to trace its popular 100% rainforest alliance certified Zoégas coffee brand (Difrancesco et al., 2022). Working with the Nespresso AAA Sustainable Quality Program to reduce environmental impact, and improve the socio-economic impacts of farming, Nestlé also partnered with the Rainforest Alliance and Fairtrade to certify that their coffee supply does not leverage child labor (Nestlé,

2000). Therefore, traceability is a key affordance offered using Blockchain technology in the food supply chain, directly influencing supplier relationships and empowering them to incorporate sustainable practices.

Visibility

Nestlé had utilized blockchain platforms to deliver visibility within its sustainability efforts. In the case of palm oil, Nestlé used satellite imagery data in the blockchain to ensure that the palm-oil production was deforestation-free, which was one of its sustainability goals (Nestlé, 2023b). The OpenSC platform allowed Nestlé to monitor and accurately provide data related to the sustainability of dairy products. Suppliers could see the coffee's journey from growing locations to the Zoégas factory, including harvest time and roasting period (Difrancesco et al., 2022).

In addition, Nestlé provides supply chain disclosure reports on its website, further adding to data visibility. Such visibility in supply chain data could foster much-needed relationship and confidence in key stakeholders and allay fears about food safety and fraud issues. Therefore, visibility is a key affordance offered using Blockchain technology in the food supply chain which can have a direct influence on improving supplier relationships, food safety and sustainability.

Validity

As explained earlier, maintaining validity requires a lot of oversight to ensure that information about a product's source is valid, accurate and complete. Blockchain can provide this highly accurate information to suppliers Although legacy supply chain management systems have solved issues with capturing and sharing information, Nestlé felt that they still suffer from limited visibility and lack of insights in real-time (Nestlé, 2020). Blockchain can centralize and help simplify and secure data validity for products and ingredients.

The examples of palm oil, dairy and coffee tracking in Nestlé's blockchain are notable examples of data validity as a key affordance of blockchain technology, facilitated through its characteristic of immutability and decentralization. Accurate information stored on the blockchain such as satellite imagery of palm oil production in Malaysia, milk production in New Zealand, and harvest time of coffee in Brazil or Rwanda helps foster supplier relationships. By sharing such valid data in the food supply chain, Nestlé has the potential to achieve its own sustainability goals and serve its suppliers well.

Discussion and Implications

The purpose of this research is to develop an affordance framework and elaborate on the application of blockchain technology in the food supply chain and its implications for supplier relationships. Our central contribution to extant literature is adapting affordance theory to develop a theoretical framework connecting the characteristics of immutability and decentralization and its influences on three affordances of blockchain technology namely traceability, visibility and validity of data. These affordances enable the firms to achieve improved supplier relationships, food safety and reduced food fraud. Our research also applied this research framework to discuss two examples in the food supply chain, the IBM and Walmart food supply chain network, and Nestlé corporation.

Due to the expanding global supply chains, ensuring food safety has become a major priority for suppliers and regulatory bodies. The World Health Organization (WHO) has calculated that approximately 420,000 individuals die yearly from food contamination, impacting approximately one out of every ten individuals

worldwide. Shockingly, WHO reports that children under the age of five face the greatest risk, with 125,000 young lives lost annually because of foodborne illnesses (Openlink, 2023). The food supply chain is saddled with fundamental challenges such as tracking, fraud, and other issues that blockchain technology can efficiently address.

Blockchain technology can solve these challenges by creating an immutable record of every transaction in the supply chain. Blockchain provides the affordances of visibility, traceability, and validity thereby increasing the efficiency and effectiveness in the food supply chain, improving food safety, reducing fraud and waste. Thus, blockchain innovation can address many of these issues by giving more noteworthy straightforwardness, discernibility, and effectiveness in the food supply chain network. Furthermore, blockchain can enable more efficient and accurate management of supply chain operations, automating processes, reducing costs, and improving inventory management (Behnke & Janssen, 2020). Finally, blockchain can prevent counterfeit products from entering the supply chain, reducing food fraud incidents, such as mislabeling, adulteration, and substitution of ingredients.

We do acknowledge that there are some limitations of blockchain technology that also need to be taken into consideration. Scalability of blockchain technology appears to be one of the challenges (Casino et al., 2021; Pearson et al., 2019; Tian, 2017). Other challenges include interoperability of blockchain technology with other systems, universal acceptance of the technology, and laws and regulations that could restrict blockchain use in some countries (Iftekhar et al., 2020; Pearson et al., 2019) specifically to address issues of fair competition and security threats.

Iftekhar et. al. (2020) also recommends using private permissioned blockchain for food supply chains. Further, some food supply chains have decided to discontinue their blockchain use. Moller-Maersk and IBM have discontinued their TradeLens offering, a blockchain-enabled global trade platform. Some analysts attribute TradeLens' failure to uncertainty between shipping players, especially regarding data exchange (Maritime-Executive, 2023).

Our overall assessment however is that blockchain technology has the potential to revolutionize food supply chain networks. In the context of food supply chain, blockchain technology provides three distinct affordances that can help to improve food safety and reduce food fraud. In summarizing our study, the implications of how blockchain technology can help food supply chain are:

- **Traceability:** *Provides the capability to track the movement of food products from farm to fork. Traceability can help to identify and remove contaminated products from the supply chain and help trace the source of foodborne illnesses.*

- **Visibility:** *Provides the capability for all participants in the food supply chain to view the same information. Visibility can help to build collaboration among suppliers, and it can also help to identify and address problems early on.*
  |
- **Validity:** *Provides the capability to track accurate and complete data. Validity can help improve supply chain efficiencies, improve food safety, and prevent food fraud.*

This study has important implications for research and practice on blockchain technology in the food supply chain. Our research framework could be expanded to study more linkages to supplier benefits due to the affordances of blockchain. Further, other characteristics of blockchain could also be studied to understand their benefits in the food supply chain. In terms of implications for practitioners, as companies envision utilizing blockchain in their food supply chain, this study details through exemplar cases, adoption

strategies and practical positive outcomes, which can help them decide on their course of action. Finally, as blockchain gains prominence in food supply chain networks, the future might yield a better and more sustainable food ecosystem: as food is sourced sustainably, the environmental impact of food production is tracked better, and food safety, shortages and surpluses are predicted and handled earlier.

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