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Optimizing global food supply chains: The case for blockchain and GSI standards

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Introduction

The globalization of food supply chains (FSCs) has added significant complexity to food systems and created an information asymmetry between food producers and food consumers. As a result, a growing demand exists for greater transparency into food origins, methods of cultivation, harvesting, and production as well as labor conditions and environmental impact (Autio et al., 2017; BildtgÅrd, 2008; Donnelly, Thakur, & Sakai, 2013). Moreover, the international debate on the integrity of FSCs has intensified due to recurring incidents and crises across the five pillars of the food system (earlier referred to as the five consumer reputations): food quality, food safety, food authenticity, food defense, and food security (Fig. 17.1).

Food-related incidents across all five pillars have been amplified through social media platforms (New, 2010), creating consumer distrust.

According to the most recent Edelman Trust Barometer (ETB), trust in the food and beverage industry has declined by two points since 2019 (Global Report: Edelman Trust Barometer 2020). This decrease is significant as the trust construct in the ETB encompasses both competence and ethics. Importantly, Edelman argued that ethics (e.g., comprised of integrity, dependability, and purpose) is “three times more important to company trust than competence” (Global Report: Edelman Trust Barometer 2020). A crucial argument is made in the ETB, suggesting that while business is considered competent, only nongovernment organizations (NGOs) are considered ethical. This claim may have a profound impact on FSCs and strongly suggests that in order to regain citizen-consumer trust, food businesses must be open to feedback and criticisms from NGOs. This point should be of particular

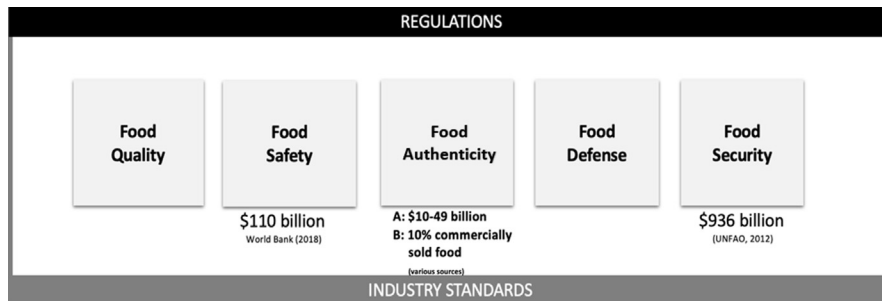


FIGURE 17.1

The five pillars of the food system.

significance to FSCs, considering that NGOs are tasked with monitoring and reporting on environmental stewardship, corruption, animal welfare, slavery, child labor, and worker rights and safety. Essentially, the journey toward food chain transparency means that food businesses must be prepared to take a proactive and continuous approach to find and reduce weaknesses in their FSCs. These weaknesses can impact all five pillars as outlined in Fig. 17.1, and monitoring and subsequent interventions will differ from pillar to pillar.

The economic costs and inefficiencies that are associated with the five pillars are significant. For instance, the [World Bank \(2018\)](#) estimated that **food safety**-related costs (e.g., lost productivity, medical costs) in low- to middle-income economies amount to USD 110 billion annually. Regarding **food security**, the United Nations Food and Agriculture Organization estimated that food security-related costs (e.g., wasted resources, economic losses) amount to USD 936 billion annually ([UNFAO, 2018](#)).

Regulatory authorities are increasingly concerned about **food security** (the adequate supply of safe, affordable, and nutritious foods that meet consumer preferences), **food defense**, and the risk of malicious attacks (terrorist acts on the food chain), as well as food fraud incidents (criminal acts related to **food authenticity**.) While the total impact of food fraud is impossible to quantify accurately, academics and industry sources suggest it ranges from USD 10–49 billion ([Manning, 2016](#); [Manning & Soon, 2016](#); [PWC, 2016](#)). The Canadian Food Inspection Agency website cites Grocery Manufacturing Association (rebranded in 2019 to Consumer Brands Association) that suggests food fraud is likely ten percent of all commercially sold foods ([CFIA, 2019](#)). Regulatory authorities must also address issues related to false information (fake news) or divisive information, which may include populist/nationalist ideals or other food sovereignty-related movements and objectives ([Borras, 2020](#)). These divisive issues have given rise to increased stakeholder distrust and a stronger emphasis on the need to improve food chain information transparency, reduce information asymmetry, and enhance trust.

FSCs are critical components of the broader food ecosystem because of their relevance to global and local populations, their role in economic prosperity, and

the vulnerabilities arising from their operations and management (Voss, Closs, Calantone, Helferich, & Speier, 2009). An FSC is a network of highly interconnected stakeholders working together to ensure the delivery of safe food products (Schiefer & Deiters, 2013). FSC actors commit to implementing a set of processes and activities that help take the food from its raw material state to the finished product (Dani, 2015). Ensuring the delivery of safe food products is an utmost priority and a primary building block for a healthy and vibrant society. Over the years, FSCs have witnessed several structural changes and a shift toward the development of more unified, integrated, and coherent relationships between stakeholders (Bourlakis & Weightman, 2008). As such, an FSC has become a “chain of trust” that extends from suppliers, producers, distributors, wholesalers, retailers, and consumers (Choi & Hong, 2002; Johnston, McCutcheon, Stuart, & Kerwood, 2004). Although FSCs represent a metaphorical “chain of trust,” the trustworthiness of the FSC is as fundamental to the integrity of our food systems as food traceability and transparency and is not without its own unique set of challenges.

The vulnerability of FSCs

FSCs are vulnerable to natural disasters, malpractices, and exploitative behavior, leading to food security concerns, reputational damage, and significant financial losses. Due to the inherent complexities of global FSCs, it is almost impossible for stakeholders to police the entire flow of materials and products and identify all possible externalities. Recurring **disruptions** (e.g., natural disasters, avian flu, swine fever, COVID-19) and consecutive food **scandals** have increased the sense of urgency in the management of FSCs (Zhong, Xu, & Wang, 2017) and negatively impacted consumer trust.

The European “horsemeat scandal” in 2013 exemplified the vulnerabilities (Yamoah & Yawson, 2014), and legal scholars from Cambridge University posited

The ability of the EU’s regulatory regime to prevent fraud on such a scale was shown to be inadequate. EU food law, with its (over) emphasis on food safety, failed to prevent the occurrence of fraud and may even have played an (unintentional) role in facilitating or enhancing it

(Barnard & O’Connor, 2017, p. 116).

The Cambridge scholars further argued that the free movement of goods within the European Union created a sense of “blind trust” in the regulatory framework, which proved to be inadequate to protect businesses and consumers from unscrupulous actors. While natural disasters and political strife are outside of the control of FSC stakeholders, to preserve food quality and food safety and minimize the risk of food fraud or malicious attacks, FSC stakeholders need to establish and agree on foundational methods for analytical science, supply chain standards, technology tools, and food safety standards.

The redesign of the FSC is necessary in order to ensure unquestionable integrity in a resilient food ecosystem. This proposal would require a foundational approach to data management and data governance to ensure sources of accurate and trusted data to enable inventory management, order management, traceability, unsafe product recall, and measures to protect against food fraud. Failure to do so will result in continued consumer distrust and economic loss. Notably, a report by [GS1 UK et al. \(2009\)](#) reported that eighty percent of United Kingdom retailers had inconsistent product data, estimated to cost UKP 700 million in profit erosion over 5 years and a further UKP 300 million in lost sales.

Blockchain Technology

The recent emergence of Blockchain technology has created significant interest among scholars and practitioners in numerous disciplines. Initially, Blockchain technology was heralded as a radical innovation laden with a strong appeal to the financial sector, particularly in the use of cryptocurrencies ([Nakamoto, 2008](#), p. 9). The speculation on the true identity of the pseudonymous “Satoshi Nakamoto” gave rise to suspicion on the actual creators of Bitcoin and their motives ([Lemieux, 2013](#)). Moreover, [Halaburda \(2018\)](#) argued that there is a lack of consensus on the benefits of Blockchain and, importantly, how it may fail. Further, [Rejeb, Süle, & Keogh \(2018, p. 81\)](#) argued “Ultimately, a Blockchain can be viewed as a configuration of multiple technologies, tools and methods that address a particular problem.”

Beyond the sphere of finance, Blockchain technology is considered a foundational paradigm ([Iansiti & Lakhani, 2017](#)) with the potential for significant societal benefits and improve trust between FSC actors. Blockchain technology offers several capabilities and functionalities that can significantly reshape existing practices of managing FSCs and partnerships, regardless of location, and also offers opportunities to improve efficiency, transparency, trust, and security, across a broad spectrum of business and social transactions ([Frizzo-Barker et al., 2019](#)). The technological attributes of Blockchain can combine with smart contracts to enable decentralized and self-organization to create, execute, and manage business transactions ([Schaffers, 2018](#)), creating a landscape for innovative approaches to information and collaborative systems.

Global supply chain standards

Innovations are not only merely a simple composition of technical changes in processes and procedures but also include new forms of social and organizational arrangements ([Callon, Law, & Rip, 1986](#)). The ubiquitous product bar code stands out as a significant innovation that has transformed business and society. Since the decision by US industry ([GS1, 2020](#)) to adopt the linear bar code on April 3,

1973, and the first scan of a 10-pack of Wrigley's Juicy Fruit chewing gum in Marsh's supermarket in Troy, Ohio, on June 26, 1974 (GS1, 2014), the bar code is scanned an estimated 5 billion times daily. GS1 is a not-for-profit organization tasked with managing industry-driven data and information standards (note, GS1 is not an acronym). The GS1 system of interoperable standards assigns and manages globally unique identification of firms, their locations, their products, and assets. They rely on several technology-enabled functions for data capture, data exchange, and data synchronization among FSC exchange partners. In FSCs, there is a growing need for interoperability standards to facilitate business-to-business integration. The adoption of GS1 standards-enabled Blockchain technology has the potential to enable FSC stakeholders to meet the fast-changing needs of the agri-food industry and the evolving regulatory requirements for enhanced traceability and rapid recall of unsafe goods.

Although there is a growing body of evidence concerning the benefits of Blockchain technology and its potential to align with GS1 standards for data and information (Fosso Wamba et al., 2019; Kamath, 2017; Lacity, 2018), the need remains for an extensive examination of the full potentials and limitations. The authors of this section, therefore, reviewed relevant academic literature to examine the full potential of Blockchain-enabled GS1 systems comprehensively, and therefore provide a significant contribution to the academic and practitioner literature. The diversity of Blockchain research in the food context is fragmented, and the potentials and limitations in combination with GS1 standards remain vaguely conceptualized. It is vitally essential to narrow this research gap.

This review will begin with an outline of the methodology applied to collect academic contributions to Blockchain and GS1 standards within a FSC context, followed by an in-depth analysis of the findings, concluding with potential areas for future research.

Methodology

In order to explore the full potential of a system integrating Blockchain functionalities and GS1 standards, a systematic review method based on Tranfield, Denyer, & Smart (2003) guidelines was undertaken. The systematic review was considered as a suitable method to locate, analyze, and synthesize peer-reviewed publications. Research on Blockchain technology is broad and across disciplines; however, a paucity of research specific to food chains exists (Fosso Wamba et al., 2019). Similarly, existing research on Blockchain technology and GS1 standards is a patchwork of studies with no coherent or systematic body of knowledge. Therefore, the objective of this study was to draw on existing studies and leverage their findings using content analysis to extract insights and provide a deeper understanding of the opportunities for a GS1 standards-enabled Blockchain as an FSC management framework.

Planning the review

As stated earlier, the literature on Blockchain technology and GS1 is neither well-developed nor conclusive, yet necessary to ensure successful future implementations. In order to facilitate the process of literature collection, a review protocol based on the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA) was used (Liberati et al., 2009). The PRISMA approach consists of four processes: the use of various sources to locate previous studies, the fast screening of studies and removal of duplicates, the evaluation of studies for relevance and suitability, and the final analysis of relevant publications. Fig. 17.2 illustrates the PRISMA process. To ensure unbiased results, this phase of the study was completed by researchers with no previous knowledge or association with GS1.

Conducting the review

Conducting the review began with a search for studies on Blockchain technology and GS1 standards. Reviewed publications originated from academic sources (peer-reviewed) and included journal articles, conference papers, and book chapters. Due to the nascent and limited literature on Blockchain technology and GS1 standards, we supplemented our analysis with other sources of information, including conference proceedings, gray sources, and reports.

The survey of the literature was conducted using four major scientific databases: Scopus, Web of Science, ScienceDirect, and Google Scholar. We used a combination of keywords that consisted of the following search string: “Blockchain*” AND “GS1” AND (“food chain*” OR “food supply*” OR agriculture OR agro. The Google Scholar search engine has limited functionality and allows only the full-text search field; therefore, only one search query “Blockchain* AND GS1 AND food” was used for the retrieval of relevant studies.

The titles and abstracts of publications were scanned to obtain a general overview of the study content and to assess the relevance of the material. As shown in Fig. 17.2, a total of 140 publications were found. Many of the publications were redundant due to the comprehensive coverage of Google Scholar; studies focused on Blockchain technology outside the context of food were removed. A fine-tuned selection of the publications was undertaken to ensure relevance to FSCs.

Report of findings and knowledge dissemination

Table 17.1 contains a summary of the findings based on content analysis. The final 28 documents were classified, evaluated, and found to be sufficient in narrative detail to provide an overview of publications to date, specifically related to Blockchain technology and GS1 standards.

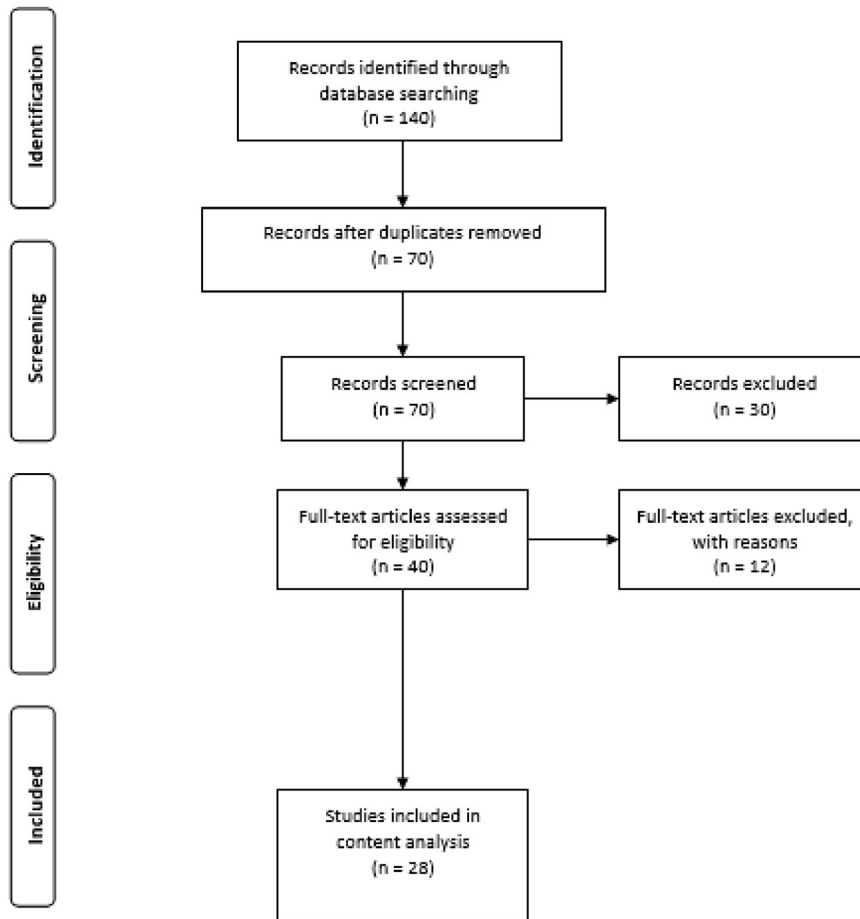


FIGURE 17.2

Graphic by authors.

The PRISMA process adapted from Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P., et al (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. Annals of Internal Medicine, 151(4), W-65.

Findings

Overview of Blockchain technology

The loss of trust in the conventional banking system following the 2008 global financial crisis laid the groundwork for the introduction of an alternative monetary system based on a novel digital currency and distributed ledger (Richter, Kraus, & Bouncken, 2015). “Satoshi Nakamoto” (a pseudonym for an unknown person,

Table 17.1 Classification of literature according to the content analysis.

Focus Publications	Traceability	Transparency	Interoperability	Data		
				Standardization	Sharing	Security
(Augustin et al., 2020)	√	—	—	—	—	—
(Ande et al., 2019)	—	—	√	—	—	√
(Bajwa et al., 2010)	√	√	√	—	√	—
(Behnke & Janssen, 2019)	√	—	—	—	√	—
(Biswas et al., 2017)	√	√	—	—	—	√
(Bouzdine-Chameeva et al., 2019)	√	√	—	√	√	—
(Chanchaichujit et al., 2019)	√	√	√	—	—	—
(Chemeltorit et al., 2018)	√	—	—	—	—	—
(Cho & Choi, 2019)	—	√	—	—	√	—
(Cousins et al., 2019)	—	—	√	—	—	—
(Dasaklis et al., 2019)	√	—	√	—	√	√
(dos Santos et al., 2019)	√	—	√	—	—	√
(Figueroa et al., 2019)	√	—	—	—	—	—
(Giusti et al., 2019)	—	√	√	√	—	√
(Helo & Shamsuzzoha, 2020)	—	—	—	√	—	—
(Iida et al., 2019)	—	—	—	—	√	—
(Kamble et al., 2019)	√	√	√	√	√	—
(Kim et al., 2018)	√	—	√	—	—	—
(Olsen & Borit, 2018)	√	√	—	—	—	√
(Pigini & Conti, 2017)	—	—	√	—	√	—
(Ray et al., 2019)	√	—	—	—	√	—
(Sander et al., 2018)	—	√	—	—	√	—
(Staples et al., 2017)	√	√	√	—	—	√
(Toyoda et al., 2017)	√	—	—	—	—	—
(Wang et al., 2019, pp. 512–523)	√	—	—	—	—	—
(Xu et al., 2019)	—	—	√	—	√	√
(Yiannas, 2018)	—	—	√	—	—	—
(Yunfeng et al., 2018)	√	—	—	—	—	—

Table, created by authors. Classification of literature according to the content analysis.

group of people, organization, or other public or private body) introduced an electronic peer-to-peer cash system called Bitcoin (Nakamoto, 2008, p. 9). The proposed system allowed for payments in Bitcoin currency, securely and without the intermediation of a trusted third party (TTP) such as a bank. The Bitcoin protocol utilizes a Blockchain, which provides an ingenious and innovative solution to the double-spending problem (i.e., where digital currency or a token is spent more than once), eliminating the need for a TTP intervention to validate the transactions. Moreover, Lacity (2018, p. 219) argued “While TTPs provide important functions, they have some serious limitations, like high transaction fees, slow settlement times, low transaction transparency, multiple versions of the truth and security vulnerabilities.”

The technology behind the Bitcoin application is known as a Blockchain. The Bitcoin Blockchain is a distributed database (or distributed ledger) implemented on public, untrusted networks (Kano & Nakajima, 2018) with a cryptographic signature (hash) that is resistant to falsification through repeated hashing and a consensus algorithm (Syilm, Liu, Marcelo, & Fontelo, 2018). Blockchain technology is engineered in a way that parties previously unknown to each other can jointly generate and maintain a database of records (information) and can correct and complete transactions, which are fully distributed across several nodes (i.e., computers), validated using consensus of independent verifiers (Tijan, Aksentijević, Ivanić, & Jardas, 2019). Blockchain is categorized under the distributed ledger technology family and is characterized by a peer-to-peer network and a decentralized distributed database, as depicted in Fig. 17.3.

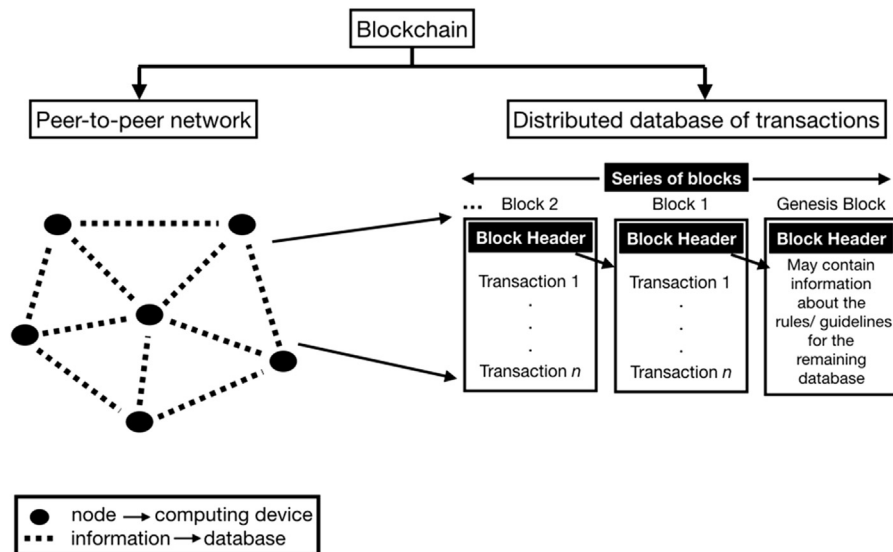


FIGURE 17.3

A diagrammatic representation of Blockchain technology.

Graphic by authors.

According to Lemieux (2016), the nodes within a Blockchain work collectively as one system to store encrypted sequences of transactional records as a single chained unit or block. Nodes in a Blockchain network can either be validator nodes (miners in Ethereum and Bitcoin) that participate in the consensus mechanism or nonvalidator nodes (referred to only as nodes). When any node wants to add a transaction to the ledger, the transaction of interest is broadcast to all nodes in the peer-to-peer network. Transactions are then collected into a block, where the addition to the Blockchain necessitates a consensus mechanism. Validators compete to have their local block to be the next addition to the Blockchain. The way blocks are constructed and propagated in the system enables the traceback of the whole chain of valid network activities back to the genesis block initiated in the Blockchain.

Furthermore, the consensus methodology employed by the underlying Blockchain platform designates the validator, whose block gets added to the Blockchain with the others remaining in the queue and participating in the next round of consensus. The validator node gains an incentive for updating the Blockchain database (Nakamoto, 2008, p. 9). The Blockchain may impose restrictions on reading the data and the flexibility to become a validator to write to the Blockchain, depending upon whether the Blockchain is permissioned or permission-less.

A consensus algorithm enables secure updating of the Blockchain data, which is governed by a set of rules specific to the Blockchain platform. This right to update the Blockchain data is distributed among the economic set (Buterin, 2014b), a group of users who can update the Blockchain based on a set of rules. The economic set is intended to be decentralized with no collusion within the set (a group of users) in order to form a majority, even though they might have a large amount of capital and financial incentives. The Blockchain platforms that have emerged employ one of the following decentralized economic sets; however, each example might utilize a different set of consensus algorithms:

Owners of Computing Power: This set employs Proof-of-Work (POW) as a consensus algorithm observed in Blockchain platforms like Bitcoin and Ethereum. Each block header in the Blockchain has a string of random data called a nonce attached to them (Nakamoto, 2008, p. 9). The miners (validators) need to search for this random string such that when attached to the block, the hash of the block has a certain number of leading zeros and the miner who can find the nonce is designated to add his local block to the Blockchain accompanied by the generation of a new cryptocurrency. This process is called mining. Mining involves expensive computations leading to (often massive) wastage of computational power and electricity, undesirable from an ecological point of view (O'Dwyer & Malone, 2014), and resulting in a small exclusive set of users for mining. This exclusivity, however, goes against the idea of having a decentralized set leading Blockchain platforms to employ other means of arriving at a consensus.

Stakeholders: This set employs the different variants of the Proof-of-Stake (POS) consensus mechanism. POS is a more just system than POW, as the

computational resources required to accomplish mining or validation can be done through any computer. Ethereum POS requires the miner or the validator to lock a certain amount of their coins in the currency of the Blockchain platform to verify the block. This locked number of coins is called a stake. Computational power is required to verify whether a validator owns a certain percentage of the coins in the available currency or not. There are several proposals for POS, as POS enables an improved decentralized set, takes power out of the hands of a small exclusive group of validators, and distributes the work evenly across the Blockchain. In Ethereum POS, the probability of mining the block is proportional to the validator's stake (EthHub, 2020) just as in POW, and it is proportional to the computational hashing power. As long as a validator is mining, the stake owned by him remains locked. A downside of this consensus mechanism is that the richest validators are accorded a higher priority. The mechanism does, however, encourage more community participation than many other methods. Other consensus protocols include the traditional Byzantine Fault Tolerance theory (Sousa et al., 2018), where the economic set needs to be sampled for the total number of nodes. Here, the set most commonly used is stakeholders. Hence, such protocols can be considered as subcategories of POS.

A User's Social Network: This is used in Ripple and Stellar consensus protocols. The Ripple protocol, for example, requires a node to define a unique node list (UNL), which contains a list of other Ripple nodes that the defining node is confident would not work against it. A node consults other nodes in its UNL to achieve consensus. Consensus happens in multiple rounds with a node declaring a set of transactions in a "candidate set," which is sent to other nodes in the UNL. Nodes in the UNL validate the transactions, vote on them, and broadcast the votes. The initiating node then refines the "candidate set" based on the votes received to include the transactions getting the most significant number of votes for the next round. This process continues until a "candidate set" receives 80% votes from all the nodes in the UNL, and then it becomes a valid block in the Ripple Blockchain.

Blockchain as a food supply chain disruptor

Blockchain technologies are considered a new type of disruptive Internet technology (Pan, Song, Ai, & Ming, 2019) and an essential enabler of large-scale societal and economic changes (Swan, 2015; Tapscott & Tapscott, 2017). The rationale for this argument is due to its complex technical constructs (Hughes et al., 2019), such as the immutability of transactions, security, confidentiality, consensual mechanisms, and the automation capabilities enabled by smart contracts. The latter is heralded as the most important application of Blockchain (the integrity of the code in smart contracts requires quality assurance and rigorous testing). By definition, a smart contract is a computer program that formalizes relationships over computer networks (Szabo, 1996, 1997). Although smart contracts predate Bitcoin/Blockchain by a decade and

do not need a Blockchain to function (Halaburda, 2018), a Blockchain-based smart contract is executed on a Blockchain with a consensus mechanism determining its correct execution. A wide range of applications can be implemented using Smart contracts, including gaming, financial, notary, or computation (Bartoletti & Pompianu, 2017). The use of smart contracts in the FSC industry can help to verify digital documents (e.g., certificates such as organic or halal) as well as determine the provenance (source or origin) of specific data. In a cold chain scenario, Rejeb et al. (2019) argued that smart contracts connected to IoT devices could help to preserve the quality and safety of goods in transit. For example, temperature tolerances embedded into the smart contract can trigger in-transit alerts and facilitate shipment acceptance or rejection based on preset parameters in the smart contract. The first platform for implementing smart contracts was Ethereum (Buterin, 2014a, pp. 1–36), although most platforms today cater to smart contracts. Therefore, similar to the radical transformations brought by the Internet to individuals and corporate activities, the emergence of Blockchain provides opportunities that can broadly impact supply chain processes (Fosso Wamba et al., 2020; Queiroz, Telles, & Bonilla, 2019).

In order to understand the implications of Blockchain technology for food chains, it is essential to realize the potentials of its conjunction with GS1 standards. While the technology is still in a nascent stage of development and deployment, it is worthwhile to draw attention to the potential alignment of Blockchain technology with GS1 standards as proof of their success, and universal adoption is very likely to prevail in the future.

Potentials of Blockchain-GS1 alignment in the FSC

Defining traceability

Traceability is a multifaceted construct that is crucially important in FSCs and has received considerable attention through its application in the ISO 9000/BS 5750 quality standards (Cheng & Simmons, 1994). Scholars have stressed the importance and value of traceability in global FSCs (Charlier & Valceschini, 2008; Roth, Tsay, Pullman, & Gray, 2008). Broadly, traceability refers to the ability to track the flow of products and their attributes throughout the entire production process steps and supply chain (Golan et al., 2004). Furthermore, Olsen and Borit (2013) completed a comprehensive review of traceability across academic literature, industry standards, and regulations and argued that the various definitions of traceability are inconsistent and confusing, often with vague or recursive usage of terms such as “trace.” They provide a comprehensive definition: “The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications” (Olsen and Borit, 2013, p. 148).

The GS1 Global Traceability Standard (GS1, 2017c: 6) aligns with the ISO 9001: 2015 definition “Traceability is the ability to trace the history, application or location

of an object [ISO 9001:2015]. When considering a product or a service, traceability can relate to origin of materials and parts; processing history; distribution and location of the product or service after delivery.”

Traceability is also defined as “part of logistics management that capture, store, and transmit adequate information about a food, feed, food-producing 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 & Gebresenbet, 2013, p. 35).

The role of technology

In the FSC context, a fundamental goal is to maintain a high level of food traceability to increase consumer trust and confidence in food products and to ensure proper documentation of the food for safety, regulatory, and financial purposes (Mahalik & Kim, 2016). Technology has played an increasingly critical role in food traceability over the past two decades (Hollands et al., 2018). For instance, radio frequency identification (RFID) has been adopted in some FSCs to enable non-line-of-sight identification of products to enhance end-to-end food traceability (Kelepouris et al., 2007). Walmart achieved significant efficiency gains by deploying drones in combination with RFID inside a warehouse for inventory control (Companik, Gravier, & Farris, 2018). However, technology applications for food traceability are fragmented, often proprietary and noninteroperable, and have enabled trading partners to capture only certain aspects of the FSC. As such, a holistic understanding of how agri-food businesses can better track the flow of food products and related information in extended, globalized FSCs is still in a nascent stage of development. For instance, Malhotra, Gosain, & El Sawy (2007) suggested it is imperative to adopt a more comprehensive approach of traceability that extends from source to final consumers in order to obtain a full understanding of information processing and sharing among supply chain stakeholders. In this regard, Blockchain technology brings substantial improvements in transparency and trust in food traceability (Behnke & Janssen, 2019; Biswas, Muthukkumarasamy, & Tan, 2017; Sander, Semeijn, & Mahr, 2018). However, arguments from many solution providers regarding traceability from “farm to fork” are a flawed concept as privacy law restricts tracking products forward to consumers. In this regard, tracking (to track forward) from farm to fork is impossible unless the consumer is a member of a retailers’ loyalty program. However, tracing (to trace backward) from “fork to farm” is a feasible concept enabled by a consumer scanning a GS1-centric bar code or another code provided by the brand (e.g., proprietary QR code). Hence, farm-to-fork transparency is a more useful description of what is feasible (as opposed to farm-to-fork traceability). While a Blockchain is not necessarily needed for this function, depending on the complexity of the supply chain, a Blockchain that has immutable information (e.g., the original halal or organic certificate from the authoritative source) could improve the integrity of data and information provenance.

Blockchain is heralded as the new “Internet layer of value,” providing the trinity of traceability, trust, and transparency to transactions involving data or physical goods and facilitating authentication, validation, traceability, and registration (Lima, 2018; Olsen & Borit, 2018). The application of GS1 standards with Blockchain technology integration enables global solutions linking identification standards for firms, locations, products, and assets with Blockchains transactional integrity. Thus, the combination of Blockchain and GS1 standards could respond to the emerging and more stringent regulatory requirements for enhanced forms of traceability in FSCs (Kim, Hilton, Burks, & Reyes, 2018).

A Blockchain can be configured to provide complete information on FSC processes, which is helpful to verify compliance to specifications and to trace a product to its source in adverse events (such as a consumer safety recall). This capability enables Blockchain-based applications to solve problems plaguing several domains, including the FSC, where verified and nonrepudiated data are vital across all segments to enable the functioning of the entire FSC as a unit. Within the GS1 standards framework, food traceability is industry-defined and industry-approved and includes categorizations of traceability attributes. These include the need to assign unique identifiers for each product or product class and group them to traceable resource unit (Behnke & Janssen, 2019).

FSC actors are both a **data creator** (i.e., they are the authoritative source of a data attribute) and a **data user** (i.e., a custodian of data created by other parties such as an upstream supplier). Data are created and used in the sequential order of farming, harvesting, production, packaging, distribution, and retailing. In an optimized FSC, the various exchange parties must be interconnected through a common set of interoperable data standards to ensure the data created and used provide a shared understanding of the data attributes and rules (rules on data creation and sharing are encompassed within GS1 standards).

A Blockchain can be configured to add value in FSCs by creating a platform with access and control of immutable data, which is not subject to egregious manipulation. Moreover, Blockchain technology can overcome the weaknesses created by the decades-old compliance to the minimum regulatory traceability requirements, such as registering the identity of the exchange party who is the source of inbound goods and registering the identity of the exchange party who is the recipient of outbound goods. This process is known as “one-up/one-down” traceability (Wang et al., 2019, pp. 512–523) and essentially means that exchange parties in an FSC have no visibility on products outside of their immediate exchange partners.

Blockchain technology enables FSC exchange partners to maintain food traceability by providing a secure, unfalsifiable, and complete history of food products from farm to retail (Molding, 2019). Unlike logistics-oriented traceability, the application of Blockchain and GS1 standards can create attribute-oriented traceability, which is not only concerned with the physical flow of food products but also tracks other crucial information, including product quality and safety-related information (Skilton & Robinson, 2009). On the latter point, food business operators always seek competitive advantage and premium pricing through the product (e.g., quality)

or process differentiation claims (e.g., organically produced, cage-free eggs). This is in response to research indicating that an increasing segment of consumers will seek out food products best aligning with their lifestyle preferences such as vegetarian, vegan, or social and ethical values such as fair trade, organic, or cage-free (Beulens, Broens, Folstar, & Hofstede, 2005; Roe & Sheldon, 2007; Vellema, Loorbach, & Van Notten, 2006; Yoo, Parameswaran, & Kishore, 2015). In Fig. 17.4 below, Keogh (2018) outlines the essential traceability functions and distinguishes the supply chain flow of traceability event data versus the assurance flow of credence attributes such as food quality and food safety certification. For instance, in economic theory, goods are considered as comprising of ordinary, search, experience, or credence attributes (Darby & Karni, 1973; Nelson, 1970). Goods classified as ordinary (e.g., petrol or diesel) have well-known characteristics and known sources and locations to locate and purchase.

Regarding search, it refers to goods where the consumer can easily access trusted sources of information about the attributes of the product before purchase and at no cost. Search is “costless” per se and can vary from inspecting and trying on clothes before buying or going online to find out about a food product, including its ingredients, package size, recipes, or price. In the example of inspecting clothes before purchase, Dulleck, Kerschbamer, & Sutter (2009) differentiate this example as “search” from “experience” by arguing that experience entails unknown characteristics of the good that are revealed only after purchase (e.g., the actual quality of materials, whether it fades after washing).

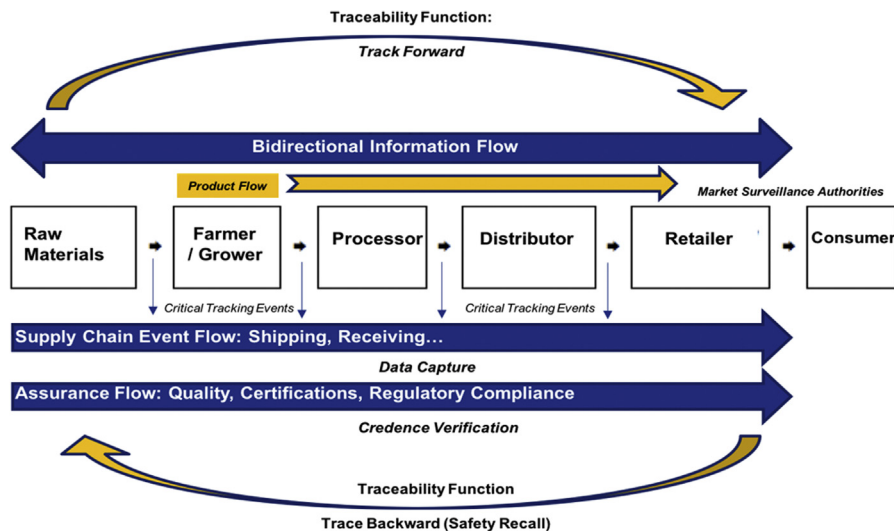


FIGURE 17.4

FSC product and information flows.

Created by author in Keogh, J. G. (2018). Blockchain, provenance, traceability & chain of custody. Retrieved from <https://www.linkedin.com/pulse/Blockchain-provenance-traceability-chain-custody-john-g-keogh/>.

Products classified as experience goods have attribute claims such as the product is tasty, flavorful, nutritious, or health-related such as lowers cholesterol and requires the product to be tasted or consumed to verify the claim, which may take time (e.g., lowers cholesterol). Verifying the experience attributes may be free if test driving a car or receiving a sample or taster of a food product in a store. Nevertheless, test driving or sampling will not confirm how the product will perform over time. Generally speaking, verifying experience attributes of food is not free, and it may take considerable time (and likely expense) to verify the claim.

Credence claims (Darby and Karni, 1973) are characterized by asymmetric information between food producers and food consumers. The reason for this is because credence attributes are either intrinsic to the product (e.g., food quality, food safety) or extrinsic methods of processing (e.g., organic, halal, kosher), and consumers cannot verify these claims before or after purchase (Dulleck et al., 2009). In this regard, a Blockchain offers a significant advancement in how credence claims flow (see Fig. 17.4) and are added to a product or batch/lot # record. For instance, the immutability of the data means that a brand owner can add a record such as a third-party certificate (e.g., laboratory analysis verifying a vegan claim or a USDA Organic certificate), but they cannot edit or change it. This feature adds much-needed integrity to FSCs and enhances transparency and consumer trust, especially if the third-party data are made available for consumers to query. In this context, the combination of GS1 standards and a Blockchain provides a consumer with the capability to scan a food product and query its digital record to verify credence claims.

At a more detailed level, the fragmentation of FSCs and their geographic dispersion illustrates the need for Blockchain and GS1 for achieving an optimal granularity level of traceability units (Dasaklis, Casino, & Patsakis., 2019). As such, the combination of Blockchain can help in the assurance of food quality and safety, providing secure (Toyoda, Takis Mathiopoulous, Sasase, & Ohtsuki, 2017), precise, and real-time traceability of products. Moreover, the speed of food authentication processes makes Blockchain a potential enabler of a proactive food system—a key catalyst for anticipating risky situations and taking the necessary preventative measures. Triggering automatic and immediate actions in the FSC has been an impetus for large corporations to adopt Blockchain technology; for example, Walmart leverages GS1 standards and Blockchain technology, defining the data attributes to be entered into their preferred Blockchain system, such as the attributes defined under the Produce Traceability Initiative (PTI, 2020). Using GS1 standards as a foundational layer, Walmart tracks pork meat and pallets of mangoes, tagged with unique numeric identifiers in China and the United States. Walmart has demonstrated the significant value of a GS1-enabled Blockchain, reducing both business and consumer risk in a product safety recall. More specifically, Walmart simulated a product safety recall for mangoes, and this exercise suggested a reduction in time to execute the product safety recall from 7 days pre-Blockchain to 2.2 s using a Blockchain (Kamath, 2017).

The contribution of GS1 to the de facto individualization of food products has motivated the study of dos Santos, Torrisi, Yamada, & Pantoni (2019), who examine

the traceability requirements in recipe-based foods and propose whole-chain traceability with a focus on ingredient certification. With the use of Blockchain technology, it is possible to verify the source of any batch or a lot number of ingredients. Kim et al. (2018) developed an application called “Food Bytes” using Blockchain technology and enabling consumers to validate and verify specific quality attributes of their foods (e.g., organic) by accessing curated GS1 standard data from mobile devices, thereby increasing ease of consumer usability and ultimately trust. Blockchain technology can help FSC partners develop best practices for traceability and to curb fraudulent and deceptive actions as well as the adulteration of food products. To solve these issues, Staples et al. (2017) develop a traceability system based on HACCP, GS1, and Blockchain technology in order to guarantee reliable traceability of the swine supply chain. In their proposed system, GS1 aids in the coordination of supply chain information, and Blockchain is applied to secure food traceability.

Food chain interoperability

A pressing challenge facing FSCs is the need to coordinate information exchange across several types of commodities, transportation modes, and information systems. By analogy, a similar need was resolved in the healthcare industry through the implementation of Electronic Health Records (EHR) to provide access to an individual patient’s records across all subdomains catering to the patient. The healthcare industry is presently working on enhancing EHR through the deployment of Blockchain to serve as a decentralized data repository for preserving data integrity, security, and ease of management (Shahnaz, Qamar, & Khalid, 2019). Closely resembling the role and function of the EHR in the healthcare industry, the creation of a Digital Food Record (DFR) is vital for FSCs to facilitate whole-chain traceability, interoperability, linking the different actors and data creators in the chain, and enhancing trust in the market on each product delivered.

FSC operators need access to business-critical data at an aggregated level to drive their business strategy and operational decisions, and many of the organizations operate at the global, international, or national levels. Data digitization and collaboration efforts of FSC organizations are essential to enable actionable decisions by the broader food industry. Currently, much of the data currently exist as siloed, disparate sources that are not easily accessible; including data related to trade (crop shortages/overages), market prices, import/export transaction data, or real-time data on pests, disease or weather patterns, and forecasts. With this in mind, and acknowledging the need for transparent and trusted data sharing, the Dutch horticulture and food domain created “HortiCube,” an integrated platform to enable seamless sharing of data and enable semantic interoperability (Verhoosel, van Bekkum, & Verwaart, 2018). The platform provides “an application programming interface (API) that is based on the Open Data Protocol (OData). Via this interface, application developers can request three forms of information; data sources available, data contained in the source, and the data values from these data sources (Verhoosel et al., 2018, p. 102).

The US Food and Drug Administration is currently implementing the Food Safety Modernization Act (FSMA) with emphasis on the need for technological tools to accomplish interoperability and collaboration in their “New Era of Smarter Food Safety” (FDA, 2019). In order to enable traceability as envisioned in FSMA, a solution is required that incorporates multiple technologies, including IoT devices. Blockchain is envisioned as a platform of choice in accordance with its characteristic of immutability to prevent the corruption of data (Khan, 2018). Ecosystems suited for the application of Blockchain technology are those consisting of an increasing set of distributed nodes that need a standard approach and a cohesive plan to ensure interoperability. More precisely, FSCs comprised of various partners working collaboratively to meet the demands of various customer profiles, where collaboration necessitates an exchange of data (Mertins et al., 2012); furthermore, the data should be interchanged in real-time and verified to be originating from the designated source. Interoperability is a precursor of robust FSCs that can withstand market demands by providing small and medium enterprises with the necessary information to decide on the progress of any product within the supply chain and ensure the advancement of safe products to the end consumer. Blockchain technology enables an improved level of interoperability as FSC actors would be able to communicate real-time information (Bouzdine-Chameeva, Jaegler, & Tesson, 2019), coordinate functions, and synchronize data exchanges (Bajwa, Prewett, & Shavers, 2010; Behnke & Janssen, 2019). The potential interoperability provided by Blockchains can be realized through the implementation of GS1 standards. Specifically, the Electronic Product Code Information Standard (EPCIS), which can be used to ensure the documentation of all FSC events in an understandable form and the aggregation of food products into higher logistic units, business transactions, or other information related to the quantity of food products and their types (Xu, Weber, & Staples, 2019). A recent study by the Institute of Food Technologists found evidence that technology providers faced difficulty in collaborating to determine the origin or the recipients of a contaminated product (Bhatt & Zhang, 2013). Hence, the novel approach of Blockchain provides a specific emphasis on interoperability between disparate FSC systems, allowing technology providers to design robust platforms that ensure interoperable and end-to-end product traceability.

The use of IoT devices allow organizations within FSCs to send and receive data; however, the authenticity of the data still needs to be ascertained. A compounding factor is the technological complexity of FSCs (Ahtonen & Virolainen, 2009), due to the reliance on siloed systems that hamper collaboration and efficient flow of information. However, Blockchain architecture can accommodate interoperability standards at the variable periphery (the IoT devices) and other technologies used to connect FSC processes (Augustin, Sanguansri, Fox, Cobiac, & Cole, 2020). Blockchain is envisaged as a powerful tool (Ande, Adebisi, Hammoudeh, & Saleem, 2019) and an appropriate medium to store the data from IoT devices since it provides seamless authentication, security, protection against attacks, and ease of deployment among other potential advantages (Fernández-Caramés & Fraga-Lamas, 2018).

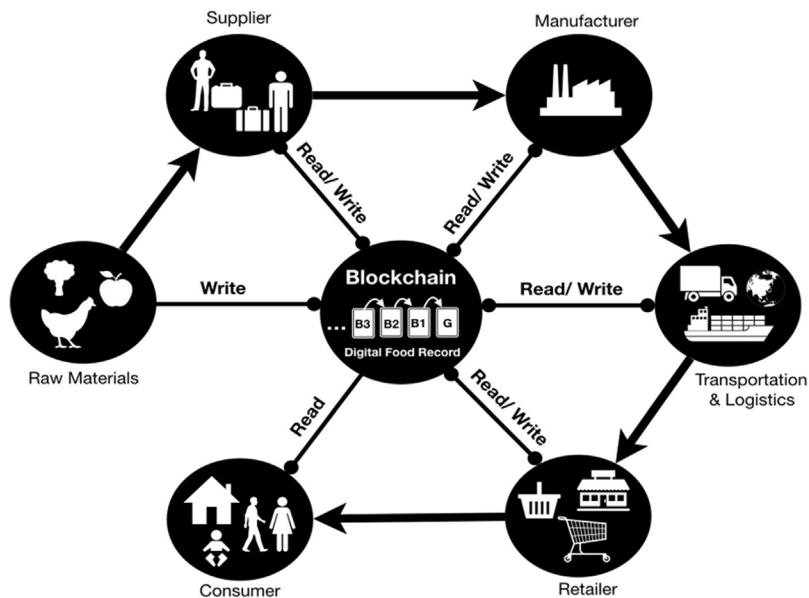


FIGURE 17.5

Blockchain: The FSC Interoperability Ecosystem

Created by author.

For FSC, Blockchain is seen as the foundational technology for the sharing and distribution (read and write) of data by the organizations comprising the ecosystem, as shown in Fig. 17.5. In this model, consumers can read data for any product and trace the entire path from the origin to the destination while relying upon the immutability of Blockchain to protect the data from any tampering. Supply chain data are stored as a DFR in the various blocks (e.g., B1, B2, B3) that comprise the Blockchain. The first block represented by G in Fig. 17.3 refers to the genesis block, which functions as a prototype for all the other blocks in the Blockchain.

GS1, traceability, and Blockchain

GS1 ratified version 2.0 of the GS1 Global Traceability Standard (GS1, 2017b), documenting the business process and system requirements for full-chain traceability. The document is generic by design with supplemental, industry-specific documents developed separately. Of interest to FSCs are

- **GS1 Global Meat and Poultry Traceability Guideline** (legacy, developed for GS1 Global Traceability Standard 1.3.0) (GS1, 2015a)
- **GS1 Foundation for Fish, Seafood and Aquaculture Traceability Guideline** (GS1, 2019a)

- **Traceability for Fresh Fruits and Vegetables-Implementation Guide** (legacy, developed for GS1 Global Traceability Standard 1.3.0) (GS1, 2015b)
- **GS1 Global Traceability Compliance Criteria for Food Application Standard** (legacy, developed for GS1 Global Traceability Standard 1.3.0) (GS1, 2016b)

Together, these documents provide comprehensive guidance to FSCs on the implementation of a traceability framework. Figs. 17.6 and 17.7 below indicate a single and multiple company view of traceability data generation.

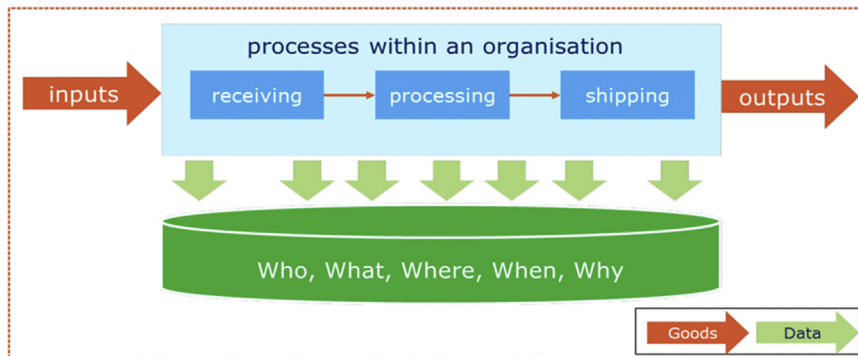


FIGURE 17.6

Generation of traceability data—a single company view.

Source: (GS1, 2017a).

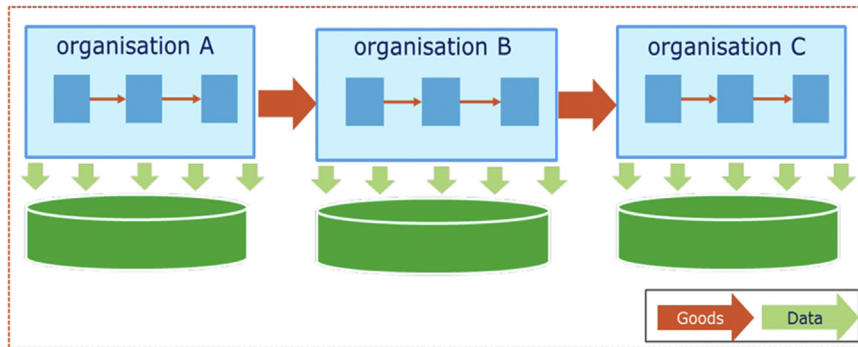


FIGURE 17.7

Generation of traceability data in a multiparty supply chain

(GS1, 2017a)

Underlying the GS1 traceability standard is the GS1 EPCIS (GS1, 2016a), which defines traceability as an ordered collection of events that comprise four key dimensions:

- **What**-the subject of the event, either a specific object (EPC) or a class of object (EPC class) and a quantity
- **When**-the time at which the event occurred
- **Where**-the location where the event took place
- **Why**-the business context of the event

The GS1 Global Traceability Standard adds a fifth dimension, “who,” to identify the parties involved. This can be substantially different from the “where” dimension, as a single location (e.g., a third-party warehouse) may be associated with multiple, independent parties.

EPCIS is supplemented by the Core Business Vocabulary Standard (GS1, 2017a), which specifies the structure of vocabularies and specific values for the vocabulary elements to be utilized in conjunction with the GS1 EPCIS standard.

Implementing EPCIS

EPCIS is a standard that defines the type and structure of events and a mechanism for querying the repository. Assuming that all parties publish to a common EPCIS repository (centralized approach) or that all parties make their repositories available (open approach), traceability is simply the process of querying events, analyzing them, and querying subsequent events until all relevant data are retrieved.

In practice, neither the centralized nor open approach is possible. In the centralized approach, multiple, competing repositories will naturally prevent a single, centralized repository from ever being realized. Even if such a model were to be supported in the short term by key players in the traceability ecosystem, as more and more players are added, the odds of one or more of them already having used a competing repository grows. In the open approach, not all parties will be willing to share all data with all others, especially competitors. Depending on the nature of the party querying the data or the nature of the query itself, the response may be no records, some records, or all records satisfying the query. For either approach, there is the question of data integrity: can the system prove that the traceability data have not been tampered with?

Blockchain is a potential solution to these problems. As a decentralized platform, Blockchain integration could provide EPCIS solution providers with a way of sharing data in a secure fashion. Furthermore, the sequential, immutable nature of the Blockchain platform either ensures that the data cannot be changed or provides a mechanism for verifying that it has not been tampered with.

The critical question is, what exactly gets stored on the Blockchain? The options discussed by GS1 in a white paper on a Blockchain (GS1, 2019b) are

- Fully formed, cryptographically signed plain text event data, which raises concerns about scalability, performance, and security if full events are written to a ledger;
- A cryptographic hash of the data that has little meaning by itself. This requires off-chain data exchange via a separate traceability application and a hash comparison to verify that data have not been altered since the hash was written to the ledger; and
- A cryptographic hash of the data and a pointer to off-chain data. This is the same as the above point with a pointer to the off-chain data source. Such an approach can enable the ledger to act as part of a discovery mechanism for parties who need to communicate and share data.

This then leads to the question of the accessibility of the data:

Public: Everyone sees all transactions;

Private: This includes a permission layer that makes transactions viewable to only approved parties.

Blockchain integration challenges

Integrating EPCIS (or any other data sharing standard) with Blockchain often presents significant challenges:

In most cases, volumetric analysis can reveal sensitive business intelligence even without examining the data. For example, if company X is currently publishing 1000 records per day, and next year at the same time it is publishing only 800, it is reasonable to assume that company X's volume is down by 20% year over year.

Revealing the subject of an event (the “what” dimension) can reveal who is handling the expensive product, which may be used to plan its theft or diversion.

Publishing a record in plain text makes the data available to any party that has a copy of the ledger, but not all data should be available to all parties. For example, transformation events in EPCIS record inputs partially or fully consumed to produce one or more outputs. In the food industry, this is the very nature of a recipe, which is often a closely guarded trade secret. In order to mitigate this risk, the ledger would have to be firmly held by a limited number of parties that could enforce proper data access controls. Even if such a system were to be implemented correctly, it means that proprietary information would still be under the control of a third party, which is a risk that many food companies would not be willing to take.

Publishing a record in an encrypted form would solve the visibility issue, but in order to do so, the industry would have to agree on how to generate the keys for the encrypted data. One option is to use the event's subject (the “what” dimension) as the key. If the identifier for the subject is sufficiently randomized, this ensures that only parties that have encountered the identifier can actually decrypt the data;

while other parties could guess at possible values of the identifier, doing so at scale can be expensive and therefore self-limiting. There would also have to be a way to identify which data are relevant to the identifier, which would mean storing something like a hash of the identifier as a key. Only those parties that know the identifier (i.e., that have observed it at some point in its traceability journey) will be able to locate the data of interest and decrypt them.

Parties could publish a hash of the record along with the record's primary key. This could then be used to validate records to ensure that they have not been tampered with, but it means that any party that wishes to query the data would have to know ahead of time where the data reside. Once queried successfully, the record's primary key would be used to lookup the hash for comparison.

To enable discovery, data consisting of the event's subject (the "what" dimension) and a pointer to a repository could be published. In essence, this is a declaration that the repository has data related to the event's subject, and a query for records related to the event's subject is likely to be successful. To further secure the discovery, the event's subject could be hashed, and that could be used as the key. Volumetric analysis is still possible with this option.

To limit volumetric analysis, data consisting of the class level of the event's subject and a pointer to a repository could be published. This is essentially a declaration that objects of a specific type have events in the repository, but it does not explicitly say how many or what specific objects they refer to. It still reveals that the company using the repository is handling the product.

Over and above all of this is the requirement that all publications be to the same type of Blockchain ledger. There are currently no interoperability standards for Blockchains. The industry would, therefore, have to settle on one, which has the same issue as settling on a single EPCIS repository. Further technical research is required to determine the viability of the various options for publishing to the Blockchain.

Discussion and conclusion

The standardization efforts in global FSCs have led to the need for best practice recommendations and common ways of managing logistics units in the food chain. The widespread use of GS1 standards reflects the tendency of food organizations to operate in an integrated manner with a universal language. This facilitates FSCs to structure and align with a cohesive approach to food traceability, empowering multidirectional information sharing, optimizing efficiencies, and added-value activities for FSC stakeholders. Moreover, the embeddedness of GS1 standards in global FSCs allows trading partners to work in an industry-regulated environment wherein food quality and food safety are of the utmost priority in delivering sustainable, authentic products to final consumers.

Today, the usage of GS1 standards is inevitable as they provide clear guidelines on how to manage and share event data across global FSCs (Figueroa, Añorga, & Arrizabalaga, 2019). This inevitability is further enhanced through the leadership of the global management board of GS1 (as of February 2020) that consists of senior executives from organizations such as Procter & Gamble, Nestle, Amazon, Google, J.M. Smucker, L'Oreal, Metro AG, Alibaba, and others. Similarly, the management board for the GS1 US organization includes senior executives from Walmart, Wegfern, Wendy's, Coca Cola, Target, Publix, Wegmans, Sysco, Massachusetts Institute of Technology, and others. The commitment of these organizations strongly supports the industry adoption of GS1 standards, and GS1 enabled Blockchain solutions as indicated by Walmart in their US-driven "fresh leafy greens" traceability initiative (Walmart, 2018). Moreover, many of these firms have announced Blockchain-related initiatives in their supply chains.

Walmart's traceability initiative reflects growing consumer concerns regarding food quality and safety and the recurring nature of product safety recalls. The combination of GS1 standards with Blockchain can provide immutable evidence of data provenance, enhance food traceability and rapid recall, and increase trust in the quality of food products. GS1 standards aid organizations in maintaining a unified view of the state of food while transitioning between processing stages across globalized and highly extended supply chains with multiple exchange parties. As such, the broad adoption of electronic traceability as identified by GS1 can endow the food industry with several capabilities, ranging from the optimization of trace-back procedures, the standardization of supply chain processes, the continuous improvement in food production activities, and the development of more efficient and holistic traceability systems.

The use of GS1 standards for the formation of interoperable and scalable food traceability systems can be reinforced with Blockchain technology. As envisioned by many food researchers, practitioners, and organizations, Blockchain technology represents a practical solution that has a positive impact on FSC collaborations and data sharing. Blockchain technology creates a more comprehensive and inclusive framework that promotes an unprecedented level of transparency and visibility of food products as they are exchanged among FSC partners. Combined with GS1 standards, Blockchain technology offers a more refined level of interoperability between exchange parties in global FSCs and facilitates a move away from the traditional or linear, stove-piped supply chains with limited data sharing.

By leveraging Blockchain, FSCs would be able to develop a management information platform that enables the active collection, transfer, storage, control, and sharing of food-related information among FSC exchange parties. The combination of Blockchain and GS1 standards can create a high level of trust because of the precision in data and information provenance, immutability, nonrepudiation, enhanced integrity, and deeper integration. The development of harmonized global FSCs gives rise to more efficient traceability systems that are capable of minimizing the impact of food safety incidents and lowering the costs and risks related to product recalls. Therefore, the integration of GS1 standards into a Blockchain can enhance the competitive advantage of FSCs.

In order to unlock the full potential from the functional components of a Blockchain and the integration of GS1 standards, several prerequisites need to be fulfilled. For example, a more uniformed and standardized model of data governance is necessary to facilitate the operations of FSCs in a globalized context. A balance between the conformance with diverse regulatory requirements and the FSC partners' requirements should be established in order to maintain a competitive position in the global market. The inter- and intraorganizational support for Blockchain implementations, including the agreement on what type of data should be shared and accessed, the establishment of clear lines of responsibilities and accountability, and the development of more organized and flexible FSCs should be considered prior to Blockchain adoption (Fosso Wamba et al., 2019).

In summary, a Blockchain is not a panacea, and non-Blockchain solutions are functioning adequately in many FSCs today. The business case or use case is crucially important when considering whether a Blockchain is required and whether its functionality adds value. Moreover, a Blockchain does not consider unethical behaviors and opportunism in global FSCs (bad character). Organizations need to consider other risk factors that could impact ex post transaction costs and reputation. Global FSC risk factors include slave labor, child labor, unsafe working conditions, animal welfare, environmental damage, deforestation and habitat loss, bribery and corruption, and various forms of opportunism such as quality cheating or falsification of laboratory or government records before they are added to a Blockchain. Product data governance and enhanced traceability can be addressed in global FSCs, but "bad character" is more difficult to detect and eliminate. Essentially, bad data and bad character are the two main enemies of trust in the food chain.

Limitations of the study and further research

This study focused narrowly on existing research combining Blockchain, GS1 standards, and food. Due to the narrow scope of the research, we did not explore all technical aspects of the fast-evolving Blockchain technology, smart contracts, or cryptography.

Further research is needed to explore the risks associated with the integrity of data entered into a Blockchain, especially situations where bad actors may use a Blockchain to establish false trust with false data. In this regard, "immutable lies" are added to a Blockchain and create a false sense of trust. Because of this potential risk, and because errors occurring in the physical flow of goods within supply chains are common (e.g., damage, shortage, theft) as well as errors in data sharing and privacy, the notion of Blockchain "mutability" should be researched further (Rejeb et al., 2019, 2020).

Further technical research is encouraged to explore the relationship between the immutability features of a Blockchain and the mutability features of the EPCIS standard. In the latter, EPCIS permits corrections where the original, erroneous record is

preserved, and the correction has a pointer to the original. Researchers should explore current EPCIS adoption challenges and whether EPCIS could provide Blockchain-to-Blockchain and Blockchain-to-legacy interoperability. The latter may mitigate the risks associated with FSC exchange partners being “forced” to adopt a single proprietary Blockchain platform or as a participant in multiple proprietary Blockchain platforms in order to trade with their business partners.

Researchers should explore if the latency of real-time data retrieval in Blockchain-based FSCs restricts consumer engagement in verifying credence claims in real time due to the complexity of retrieving block transaction history.

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Conflict of Interests

- No funding was received for this publication.
- John G. Keogh, the corresponding author, is a former executive at GS1 Canada and has not advised or worked with or for GS1 for more than 5 years.
- Kevin Dean is an independent technical consultant advising GS1.

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