Traceability Systems and Technologies for Sustainability in Food Supply Chains

M. Ramasubramaniam and A. Karthiayani

Abstract The concept of tracking and tracing food products has been a cornerstone for food safety policy since the 1990s (Sarpong, European Business Review 26:271–284, 2014). Since they became mandatory in 2000s with EU food safety laws, traceability has gained significance in the food supply chain. This article underscores the role played by traceability systems, an important driver of sustainability, in the food supply chain and explores the underlying technologies and brief overview of the barriers to their adoption. Thus, this paper paves way for future research in the traceability technologies to enable SSCM practices.

Keywords Sustainability · Food supply chain · Traceability · Traceability technology

1 Introduction

As humans, we have a moral responsibility of ensuring the survival of not just our own species but also ensure the survival of other species on this planet. Unfortunately, this responsibility is disowned by some who are in the business of servicing customers, especially in the food supply chain. The un-relented focus on fast-paced growth for the benefit of their own firms at the cost of consumers is taking its toll on the planet. There is increased incidence of foodborne illnesses and health panics among consumers. Every year, nearly 600 million people fall sick because of consumption of contaminated food, resulting in more than half-a-million deaths, reports World Health Organization.

Globally, there are a lot of documented evidence pointing to rampant food scandals. A recent analysis on 20-year data done by (Robson et al., 2020) unearthed

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K. Mathiyazhagan et al. (eds.), *Lean and Green Manufacturing*,
Management and Industrial Engineering,
https://doi.org/10.1007/978-981-16-5551-7_6

413 fraud reports in the global beef supply chains. Such scandals have a debilitating impact on human lives. For instance, in 2011 alone, nearly 50 million people got sick and nearly 3000 of them died due to foodborne diseases (Morris Jr., 2011). The consumption of contaminated bean sprouts had resulted in 37 deaths in Germany and made 3000 lives sick (Marucheck, 2011). One cannot forget the largest food recalls in history in 2008 in US by Peanut Corporation of America after many reported sick and few of them died (Layton, 2009).

China also experienced milk powder adulteration because of which nearly 3 lakh people fell ill and left at least 10 dead (Xiu, 2010). In India, Nestle faced wrath for excessive amounts of heavy metals in its Noodles (Mitra, 2017).

These illnesses occur due to both human-made and non-human-made factors. The human-made factors exacerbate this through self-discovered globalization practices. The producers and consumers are far away from each other in today's globalized world making it difficult for the consumers to be aware of the origins of the food products they consume. The processes and controls of food manufacturing are not generally known to the end consumer. This provides incentive for some of these businesses to play spoilsport in the supply chain resulting in such widespread incidents. In some cases, despite the best intentions of food manufacturing firms, the contamination of food can happen in the distribution part of the supply chain. After the notorious food scandals of 1990s, consumers started feeling the need for understanding the origins and processes of food manufacturing and this gave birth to concept of food *traceability*.

The current pandemic is a good example of non-human-made factor that is having a devastating effect on the food supply chains. Supply chains are strained beyond their capacities because food is an essential commodity (OECD, 2020). This has increased the awareness among consumers to consume safe and hygienic food and has kindled the need to know the origins and processes of food manufacturing.

Thus, traceability has gained enormous significance in recent times and the pandemic has only further reinforced its need. *Traceability*, in general, refers to *tracking*, which is determining the origin and characteristics of a particular product and *tracing*, which is collecting the history of products related to its displacement along the supply chain (Bechini, 2008).

As per the ISO 9000 (2005) standards (ISO, 2005), the definition of traceability is "*the ability to trace the history, application or location of that (product or process) which is under consideration*". The guidelines also cover the complete history of processing and distribution of products even after shipments.

But these definitions are not comprehensive in nature for such an all-pervasive term. (Bosona T, 2013) provides a very comprehensive definition to food traceability:

> Food traceability is defined as a 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.

Given this definition of traceability, we seek to understand the traceability systems and the related technologies in the food supply chain in this article. We first discuss the role of traceability and sustainability in food supply chain in Sect. 2. Then we present the methodology of the research in Sect. 3. We then explore the role played by traceability systems as a strategic and risk management levers in managing the food supply chain in Sects. 4 and 5, respectively. Then a framework on traceability system implementation is discussed in Sect. 6. Section 7 uncovers the various technology standards in use for implementing traceability. Section 8 underscores the challenges in its implementation. In Sect. 9, we highlight some ways of mitigating these challenges and provide a way forward.

2 Traceability and Sustainability in Food Supply Chain

Sustainability as a research topic has gained prominence after the advent of globalization, as well. With supply chains underpinning the era of globalization, it is only but natural that this topic warrants enough attention, especially in the face of the widespread scandals and the focus as outlined above on the profit motive. The adoption of Sustainability focused practices in Supply Chain is termed as Sustainable supply chain management (SSCM).

The need for including the oft-neglected environmental aspects called for a comprehensive definition of this nascent field. Thus, according to (Beske et al., 2014), SSCM can be defined as:

> the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements.

The definition encompasses the length and breadth of the entire supply chain including all the stakeholders in the action. Thus, by nature, the adoption of practices that enable SSCM relies on a very complex relationship between the different stakeholders to ensure that the third dimension—environment—is taken care.

This is all easier said than done. The inclusion of the third dimension generally is viewed as conflicting and goes against the principle of Peter Drucker who strongly propagated the idea that the primary motive of a business is to "*profit*" and nothing else (Drucker, 1973). This also means there is no incentive for a firm to co-operate with another, even if they are meant to interact with one another on a regular basis in the process of engaging in the business. Thus, communication and collaboration between stakeholders in a supply chain emerge as key actions which help supply chains achieve the third dimension and eventually help them attain sustainability.

Our literature review indicates that traceability technologies possess the capability to enable tamper-proof communications and collaborations through enforcement of compatible enforcement standards (Bechini et al., 2008; Germani et al., 2015; Sarpong, 2014; Caro et al., 2018).

Thus, these technologies not only enable supply chain transparency but also have potential to increase *trust* among the supply chain partners which is a key motivating factor for sustainability (Garcia-Torres et al., 2019). Therefore, adoption of traceability technologies offers a promising means for improving the SSCM practices, increasing the SC collaboration and attaining the sustainability goal.

To the best of our knowledge, there are no studies which explore the role played by traceability systems and technologies in the food supply chain and documents the disparate technology standards and discuss their implementation challenges. We attempt to fill this gap.

3 Methodology

The review of literature for this paper started with identifying relevant keywords for database search. After brainstorming, the authors identified the following keywords:

(1) First level search: “Traceability technologies”, “Traceability System”
(2) Second level search: “Food supply chain”.

The shortlisted keywords were then used to search the prominent databases: Scopus, Google Scholar and Microsoft Academic. The details of the search process are presented in Fig. 1.

The first level keyword search resulted in a total of 6,700 results. Once the second level keyword was applied, the results narrowed down to 346 from all the databases. These articles were then manually reviewed to include peer-reviewed journal articles and other sources that are closely relevant with our topic of research. The final shortlisted 33 sources were included in this study.

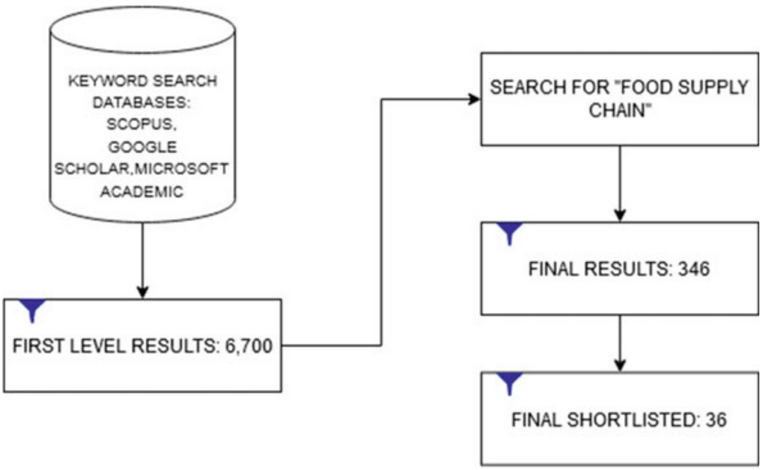

Fig. 1 Literature search process

4 Traceability as a Strategic Tool

Food supply chains in general have a tighter regulation in force. However, even with these regulations, firms which do not explicitly adopt the concept of sustainability in their SCM practices generally end up breaching the social and environmental norms (Ebinger & Omondi, 2020). Traceability can play a significant role in alleviating that because it allows us to measure the extent of social and environmental breaches at any point of the entire supply chain. Food supply chains, therefore, can leverage traceability to achieve the triple bottom line approach and thereby achieve competitive advantage.

Specifically, traceability can be beneficial to the stakeholders involved in the food supply chains through the direct measurement of product and service history. This not only improves the accuracy of record-keeping, but also makes it an effective monitoring tool. Quality control then becomes a natural consequence of traceability. Therefore, we posit that a proper implementation of traceability can significantly improve SSCM's effectiveness.

Traceability also adds a significant benefit to supply chains in terms of tracking product recalls, product safety and optimize reverse logistics processes (Chen, 2014; Hongyan Dai, 2015).

In addition, traceability has other indirect benefits. It can reduce information asymmetry in the supply chains. Indeed, it is known that effective collaboration can be hindered by the asymmetric information propagating in the supply chain (Moises, 2012). The presence of asymmetric information makes the supply chain less transparent. Thus, in the absence of traceability and a consequent less-transparent supply chain, there is an incentive for the supply chain actors to mask their real intentions while reporting the performance to their stakeholders.

4.1 Traceability as a Meta-Capability

On a more abstract level, traceability can become a meta-capability which may be effected through proper governance, collaboration among the supply chain partners and tracking and tracing of products and processes. Governance is a top-down mechanism that relies on both formal and informal controls to achieve SSCM practices. Formal controls are enforced by means of regulations and standards in the food supply chain. On the contrary, informal controls rely on *"trust"* as the delivery mechanism. Many of the studies in the past have shown trust as an important factor in effecting efficient supply chain practices (Cheng, 2008).

It is pertinent to note that governance alone cannot entail such practices. Successful governance and collaboration between supply chain actors work in tandem. Collaboration, can therefore, be viewed as another strategic tool to achieve the meta-capability. In fact, collaboration is documented as a connect between business processes and the structure of a supply chain (Vlajic, 2012). The structure includes all things technical and logistical that bring together the actors of a supply chain and significantly improves the accuracy of information. The nature of such co-operation and development can extend beyond the normal food manufacturing and extend to external processes and technologies.

Beyond governance and collaboration, a third strategic lever for traceability as a meta-capability is tracking and tracing. Of late, tracking and tracing are proving to be essential for a sustainable food supply chain (Fritz, 2009). Indeed, (Anastasiadis, Apostolidou & Michailidis, 2020) show that effective implementation of both of these mechanisms is instrumental for enhancing supply chain visibility leading to a strong sustainable supply chain performance. Recently, tracking and tracing have also been demonstrated to be effective in increasing both the formal-informal controls by reinforcing the trust and increasing the collaboration (Garcia-Torres et al., 2019). Thus, by enabling a host of strategic options, traceability is proving itself to be an effective tool in implementing SSCM practices for firms.

4.2 Tracking and Tracing and Operational Efficiency

Tracking (*forward traceability*) and Tracing (*backward traceability*) refers to the activity of collecting both upstream and downstream information in a supply chain and is effective in controlling the operations in a process, broadly termed as *chain traceability*. According to Moe (1998), chain traceability is the *"…ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales*".

It can identify and locate the historical events involved in manufacturing a food product. However, this activity can be challenging for a food supply chain because of the disconnect between structure of a supply chain and its business processes, demand volatility and incompatible global standards and may also sometimes include absence of skilled actors.

Traceability provides opportunities for firms to re-visit their competencies and knowledge of the business domain in which they operate. For instance, traceability can significantly improve the operational efficiency of a firm. The efficiency is perceived to be amplified through lower inventories, reduced lead times and lesser stock-outs and operating costs (Cousins et al., 2019).

In other words, traceability can be viewed as an all-encompassing strategic tool for enabling an organization's SSCM practices both in short-term as well as long-term.

5 Traceability as a Risk Management Tool

Traceability also acts as an effective risk management tool. Apart from being an effective risk mitigator through monitoring, it can provide a significant protection against lack of adherence to standards or certifications (Sarpong, 2014).

The globally accepted food standards are broadly classified as self-certifications and third-party certifications. Most of these certification standards expect voluntary compliance. If any party in the supply chain violate the norms, there is no legal action for it. One of the prominent self-certification standard in food supply chain is the Hazard Analysis and Critical Control Points (HACCP) (Wallace, 2011).

Organizations like the Food and Drug Administration (FDA) also require food supply chains to maintain history of sources of raw materials and destination of food products that can facilitate compliance in the long run. The objective of these enforcements is to obtain systemic information on the ability to trace a product back to its origin.

Besides these certifications, there are also third-party certifications that examine the safety of food (Codex standard), quality of food (processor standard), Agriculture practices (e.g. ISO 9000 standards). All these are unique to food supply chains.

There are other standards which are applicable for labor practices (e.g. Fairtrade standards, ETI Baseline) and Environment (e.g. IS 14000) which are required for day-day operations in connection with food manufacturing systems.

The presence of so many standards and different forms of certifications with sometimes unclear and incompatible regulations have given rise to a debate whether the certifications really drive the goal of quality control or does it incentivise the supply chain actors to be only a paper tiger (Ling & Wahab, 2020).

This fundamental conflict between governance and self-compliance of supply chain actors can be mitigated through successful implementation of traceability practices. However, one point to keep in mind is, this effectiveness cannot be improved if the implementation is improper. Therefore, a proper implementation is envisaged that can improve the overall effectiveness of the SSCM practices and thereby the sustainability. In this context, the traceability systems and technologies of food supply chain needs to be understood better and this is the focus of the subsequent two sections.

6 Traceability System in Food Supply Chains

A food supply chain consists of different actors namely Farm, Distributor, Factory, Retailer and Customer with product and process flows across their length and breadth. The traceability systems in this entire spectrum comprise of both internal and external traceability systems to enable chain traceability. While *internal traceability* refers to the *"ability to trace a product to one of the steps of a stage in the food supply chain"*, *external traceability* refers to *"ability to trace the product between any two actors or stages of the food supply chain"*. We explore the concept of food traceability system framework in the form of a Food information system which employ various traceability technologies to implement the chain traceability.

The Food Supply Chain Information System (FSIS) used for traceability (Fig. 2), hinges on the tracking and tracing abilities of a food supply chain. Tracing the products and ingredients in a food supply chain requires the use of Unique Identifiers

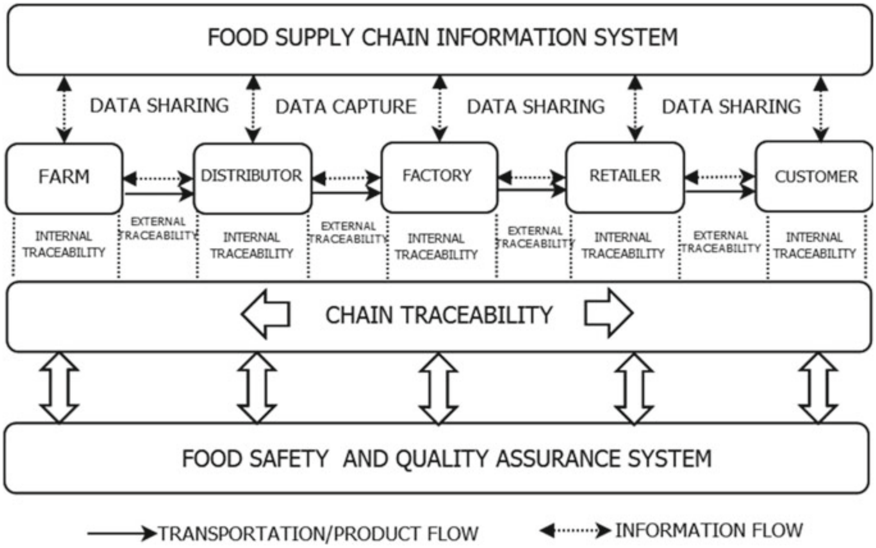

Fig. 2 Food supply chain information system (Adapted from Behnke, 2020)

which has to be defined for each Stock Keeping Unit or a group of SKUs and in general referred to as the Traceable Resource Units (TRU) (Aung, 2014).

Successful implementation of tracing requires addressing three fundamentally different TRUs:

1. Products sent in same batch consisting of same batch number, e.g. Box of cans with milk powder
2. Products which undergo the same process steps, e.g. Tomato Sauce produced with same before and same batch number data values
3. Products which are aggregated together for the purpose of logistics convenience, e.g. Cans of milk powder with different batch numbers.

These definitions imply that a TRU could in fact refer to the same batch unit or several TRUs can refer to a same batch unit if they shared same processing steps.

At the heart of the Governance mechanism, the Food Safety and Quality Assurance System (FSQAS) provides the safety and quality regulations for compliance of the food supply chain actors. The information pertaining to compliance with the regulations are stored in the Food information system.

There is a multitude of factors that determine the overall effectiveness of the traceability system. This includes the nature of business, nature of customers and market and the ingredients which are used in the supply chain. The effectiveness also relies on the extent of complexity of the traceability system. For example, number of suppliers, the characteristics of food production, distribution nature are differentiating factors of a traceability system and impacts the overall effectiveness. Further, another important contributing factor is the country-specific or product-specific systems that warrant a particular food safety regulatory compliance.

The entire Food Information system relies heavily on the technology adoption at various stages of the food supply chain. The technologies that are backbones of the Food supply chain Information System in implementing chain traceability include Data Capture and Data Sharing systems. The subsequent section throws light on these traceability implementation technologies for food supply chains.

7 Traceability Implementation Technologies in Food Supply Chains

Food processing industry by nature is a complex one. Huge volume of information gets generated in this supply chain every day. This makes the implementation a challenging task. Thus, traceability systems require an ICT infrastructure that employ advanced technologies (Fig. 3) which enable capturing such huge volume of data throughout the supply chain (Haleem, Khan and Khan, 2019).

Furthermore, implementation of traceability requires technologies that can share information across disparate networking systems with often different standards of communication. The chain traceability, therefore, is only as good as the extent of integration among these disparate systems.

This section explores the different traceability technologies which involve both data capture and data sharing mechanisms. With their varied nature in terms of

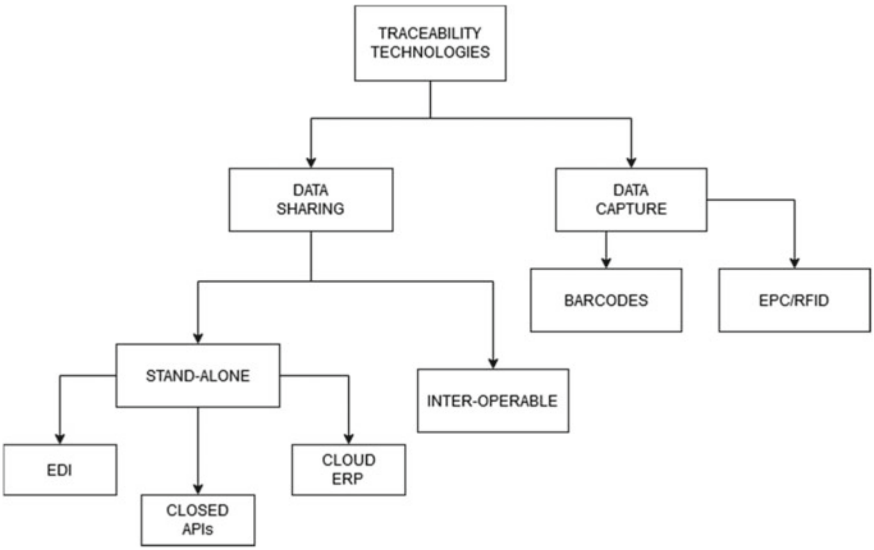

Fig. 3 Traceability technologies in food supply chains

standards, functions, and operations, these technologies complement each other in ensuring a transparent food supply chain.

7.1 Stand-Alone Systems

Stand-alone systems feature technologies that are conventional and are limited to firm-level information sharing in the enterprises. However, these are still prevalent and widely used technologies. Understanding these technologies has laid the foundation of more open and transparent inter-operable technologies.

7.1.1 EDI

The origins of traceability system implementation started with Electronic Data Interchange (EDI) that has been adopted for information sharing across the supply chains. The EDI shares the information through a network called VAN which stands for Value-Added Network. Since the technology is rudimentary, it is expensive to set up and the transaction costs occupy significant portion of the investment.

7.1.2 APIs

API is an acronym for Application Programming Interface. This gained popularity recently because it is often a small custom-built piece of software code that allows two disparate systems to communicate through electronic means. This type of technology adoption is quite popular in the seafood supply chains.

Since they are purpose-built for 2 systems, it is difficult to extend the usage for including any other system. Thus, including a third system into the information system configuration requires significant time and effort and also is an expensive proposition.

7.1.3 ERP

ERP or Enterprise Resource Planning systems have been a stronghold until recently where the internal traceability is good across the firm level. However, because there are a lot of vendors who are offering these systems, the ERP used across the different stages of the food supply chain relies on different ERP systems that are not necessarily compatible with each other.

One way of solving this information sharing problem is to introduce a cloud-based ERP system which will solve this problem to a certain extent. Indeed, many food supply chains have currently adopted these kind of systems.

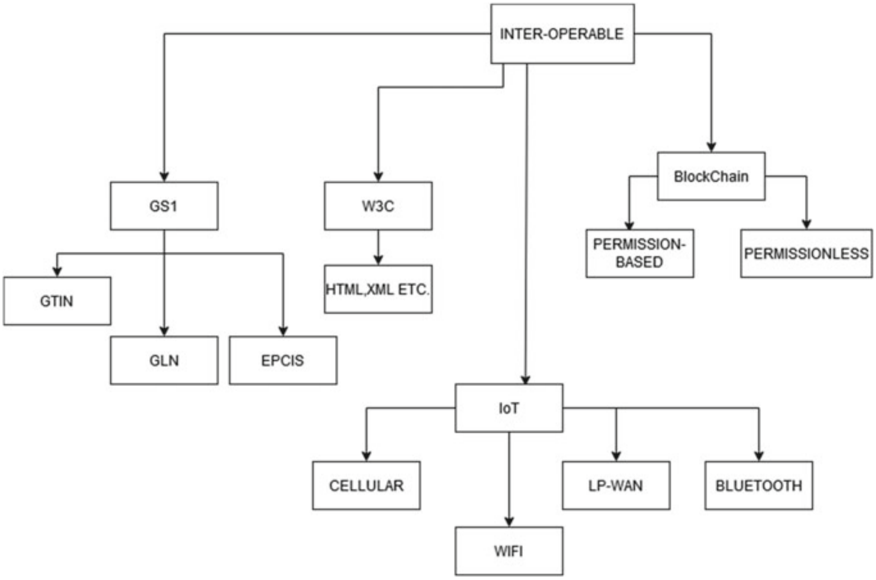

Fig. 4 Inter-operable technologies in food supply chain

In a cloud-ERP, data is entered via a browser that is stored in a cloud database. Often the ERP system is hosted by a third-party technology vendor. While, the cloud systems provide a way of data sharing without a need for a complex information system, the data is still entered manually in the browser which can take significant time and effort. Also, the system is limited in terms of location of data sharing. Any change in the location requires a modification of the information system which can be time-consuming.

7.2 Inter-Operable Technologies

The limitations of the stand-alone systems are overcome by implementing more open and scalable systems to support the tracking and tracing. The following section discusses various such systems (Fig. 4).

7.2.1 GS1

Industry inter-operability with a global connectivity across food supply chains can be enabled by the GS1 standards which precisely allow that. Specifically, the architecture of GS1 allows not only communication among different and hardware and software, they also allow supply chain processes to be integrated. Indeed, the GS1

(2014) standards allow *"interface between system components that facilitate inter-operability from components produced by different vendors"*. The standards are also vendor-neutral and platform-independent system which means a software working in windows can be compatible with a software working in linux.

Currently, SAP and IBM are testing the inter-operability using the GS1 standard. FoodLogiQ, IBM Food Trust, ripe.io and SAP, the four traceability platform providers participating, simulated a seafood supply chain using GS1 standards to identify the item being tracked and transmit the location along the supply chain. (PRN, n.d.)

7.2.2 EPCIS

EPCIS originates from EPCglobal that integrates data capture and data sharing elements. EPCIS is a specific variant of GS1 standard that enables sharing of data on the physical movement of products and ascertain the product status in the food supply chain. By providing this chain traceability, the standards allow compliance to the regulations in place. They also allow capturing different assets in movement such as physical and digital assets.

Since the standard is a variant of GS1, the adoption of this standard requires adoption of the Core Business Vocabulary (CBV) standards emphasized in GS1. The heart of traceability lies in this vocabulary which standardizes the data which is populated in various stages of the food supply chain.

In a pilot test for food traceability called "e-Trace project" (Gunnlaugsson, 2011), it was adopted in a one-day redfish catch for a groundfish processing plant in Iceland through to packaged items for distribution. Taken together, the system allowed integration of various information sources to comply with the food safety standards with provisions for pin-pointing specific points in the production process.

7.2.3 IoT

The **Internet of things** (**IoT**) is a network of physical objects or "things" which have embedded sensors and hardware that connect and exchange data with each other over the internet. In this section, we discuss the various communicative technologies in use for enabling the IoT.

LPWANs

The communication between the different types of IoT sensors is facilitated through Low-power Wide Area Networks or LPWANs which are relatively new technologies. They enable remote monitoring of products, smart metering of things and ensure worker safety and enable building management systems. However, one limitation of LPWANs is they can send only small packets of data and is useful in applications where there is no requirement for high bandwidth or real-time information.

There are many variants of LPWANs that exist today. NB-IoT, LTE-M, MYTHINGS, LoRA, SigFox, etc., are a combination of licensed and unlicensed spectrum of technologies that also have varying degree of performance in network factors.

Cellular Technology

Cellular networks are widely popular and well-tested in the consumer mobile markets. They offer a reliable communication for voice calls and video streaming applications. However, they have high operational costs and consume lot of power.

They are not capable of adoption across all the IoT applications but suited in some specific instances where things are powered by battery-operated sensors. For example, fleet management of food supply chain can be done with route planning, advanced driver assistance systems along with tracking and telematics which consume huge bandwidth of the cellular network. Future supply chain fleets are poised to use the next generation Fifth generation technologies offering significant speeds and low buffering capabilities.

Bluetooth

Bluetooth is a relatively old technology used for short-range applications. However, the advantage is that it is very prevalent and well-positioned in consumer markets with all the gadgets used in entertainment sector adopting this technology. Since, the power consumption of these devices is low, it is ideally suited for IoT applications where things inside a factory need to communicate.

One of the important grouse for widescale Bluetooth adoption was that the deployment of Bluetooth devices was not scalable. However, the Bluetooth Mesh specification which was made in 2017 aims to solve this problem especially useful in the food retail segments. These Bluetooth networks assist customers in navigating the stores and enable customized promotions.

Wi-Fi

One of the important landmarks in wireless communication is the adoption of Wi-Fi standards which provide high throughput data that can be used in enterprise level applications. In the IoT applications perspective, there is still a limitation in terms of coverage, scalability, and power consumption.

Because of the high energy requirements, Wi-Fi is not implementable for large networks with lots of battery-operated IoT sensors which are the mainstay for industrial applications and smart buildings.

But the latest Wi-Fi 6 standards can take this to next level with a greatly enhanced network bandwidth which significantly increases data consumption in dense networks. With this, the infrastructure can transform the customer experience in food supply chains.

EPC/RFID

The **Electronic Product Code** (**EPC**) provides unique identity for products across the entire food supply chain. The EPC is designed as a flexible framework to support different coding schemes including that of barcodes and in a limited way with RFID tags.

Radio Frequency Identification (RFID) transmits miniscule quantity of data pockets from an RFID tag which is read by a RFID reader kept at a close proximity. Each product in food supply chain that is manufactured can be uniquely identified using passive RFID tags.

On the contrary, traditional technologies like bar codes do not have the required capacity for a detailed identification and rather limited to only a group of food products. Attaching an RFID tag to products will enable food supply chains to track their inventory and their assets in near real-time. This greatly enhances supply chain visibility and allows for better production planning and optimizing the supply chain management. RFIDs offer extended capabilities to identify individual SKU-level items that are inside the cartons, eliminating the need for opening them.

RFID currently is widely used in the retail segment and in distribution part of logistics. In a IoT context, this can enable new applications like smart shelves, smart-checkouts and smart mirrors which opens a whole new frontier for consumer experience.

7.2.4 W3C Technology

The **World Wide Web Consortium** (**W3C**) is a consortium of internet standards otherwise termed as the World Wide Web. These standards are useful for web scripting and display of web pages that may contain content ranging from static to dynamic content which are graphic heavy. They also allow compatibility across multiple devices.

W3C standards ensure that the hardware manufacturers and software developers who adopt these standards will have their equipment and programs work on the latest web technologies. Most of the web browsers adopt the w3C standards. For instance, HTML and CSS are formats are widely used in several browsers for consistency in terms of website displays.

Javascript Web APIs, a specific form of W3C standard, are used in client-side Web Application development for Geolocation, XMLHttpRequest, and mobile widgets. To ensure cross-cultural capabilities and languages, HTML and XML are built on Unicode which enable a smooth translation from one language to the other. W3C has also published guidance for authors related to language tags.

7.2.5 BlockChain Technology

BlockChain Technology (BCT) offers a promising means of decentralized and distributed systems for executing supply chain transactions (Ebinger & Omondi, 2020). It was originally used for digital currencies such as Bitcoin and Ethereum. However, since it has the potential for use in other financial services in larger financial companies, it has garnered wide attention and resulted in lots of trials in different industries including logistics and supply chain management.

BCT also holds potential to increase the traceability and transparency of the products in the supply chain by allowing the transactions between two or more supply chain partners to be immutable without a third-party intervention. This enables a tamper-proof digital transaction apart from the decentralization and distribution characteristics. Together, these three characteristics of BCT increase the stakeholders' trust in the entire food supply chain. Trust increases the governance effectiveness through collaboration and thereby BCT plays an important role in achieving a sustainable supply chain (Ebinger & Omondi, 2020).

However, one of the drawbacks of the technology is the limitation on the transaction rates. The permission-less blockchain system limits the size of a block to be a maximum of 1 MB and allows processing rates up-to seven transactions per second. With food supply chains requiring huge volumes of transactions in a second, the current implementation of BCT is not viable. There are current pilots underway in food supply chains to improve this and make it more scalable.

With such a comprehensive set of technologies, we would only expect the food supply chain to have embraced their adoption with open hands. However, as we see in the subsequent section, there are notable barriers to the widespread adoption. Due to the brevity of the article, the authors restrict the discussion to only provide an overview of these barriers.

8 Barriers to Traceability Implementation

The food supply chain is characterised by wafer-thin margins and a lot of competition. The supply chain partners have a scepticism and do not trust the competitors. They tend to guard their SCM practices very closely which creates a lot of information asymmetry. From this context, sharing of information from a traceability perspective is only perceived as very risky venture and goes against their culture. Therefore, implementing Traceability requires a significant level of inter-business collaboration which has not been experienced in the past. Apart from these, there is a multitude of factors that hinder the implementation of traceability technologies (Marah J. Hardt, 2017):

a. *Lack of awareness* of the need for a traceability system and technology at the supply chain level.
b. *Knowledge gaps* of the chain traceability and associated digital technologies.

c. *Resource deficiencies* including that of capacity and funding issues along with technical issues of information technology systems currently in place.
d. *Logistical hurdles* in the operation of traceability systems; Broader adoption requires involvement of multiple stakeholders which makes it difficult.

All these barriers can be addressed through development of a holistic approach towards traceability implementation. Periodic training programmes and creating awareness among consumers will go a long way in overcoming these barriers.

9 Conclusion

SSCM practice adoption is critical for long-term health of humans and for the well-being of the planet. It is worrisome to note that some of the food supply chains engage in fraudulent activities that belie the broader objective with which the SSCM practices were envisaged. The deviations from the regulatory norms need monitoring and managed for potential violations.

Our study reveals that the traceability systems and technologies provide a compatible framework within which such regulations can be implemented leading to SSCM practices. These systems also provide a mechanism of providing chain traceability both internal and external leading to efficient tracking and tracing of food products across the supply chain.

The traceability systems enable tighter monitoring of regulations and at the same time bring in increased supply chain transparency, better collaboration, and increased trust. Technologies like BCT provide promise of tamper-proof supply chain transactions and uphold trust among supply chain partners thus bridging the gap between all the three aspects.

We find that Traceability, in its nascent phase, may also prove to be a significant enabler for attaining the sustainability goals through better governance and increased operational efficiency. There is little doubt that the traceability technology implementation will stand to benefit the food supply chain in the long run.

However, on the downside, the lack of awareness, prevalence of multiple certifications, compliance requirements and number of other factors require significant efforts from the food supply chain actors. In this context, FSIS can play a key role in being a catalyst for traceability implementation. Capturing the origins of product and sharing the data is fundamental at the heart of traceability technologies. The current complexity in the misalignment of various interfaces and standards of the global food supply chain actors can be overcome by increased traceability adoption and standardization by means of inter-operable technologies.

This field offers different avenues for future research. For instance, the traceability systems and technologies in food supply chain provide a ripe opportunity for the researchers to empirically analyse in detail the enablers and the barriers in their adoption which is a limitation of our study. Alternatively, one could explore the empirical connection between traceability technology adoption and the sustainability development goals. Exploring the nature and complexity of challenges in BCT adoption across different country contexts is another research direction.

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