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Blockchain in the Food Industry: Integrating Machine Learning in a Systematic Literature Review

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ABSTRACT

This study provides a systematic literature review of blockchain technology in the food industry with a supply chain lens. We identify primary and sub-themes, discuss implications and applications in terms of delivering value and propose literature-informed future research directions. This review uncovered three primary themes: a) Value Creation; b) Supply Chain Digitization; and c) Transformation. It demonstrates that digitalizing food networks with blockchain technology may benefit from increased stakeholder involvement and data visibility to gain competitive advantage. Beyond the theoretical contributions, this research provides a methodological contribution by demonstrating the uses of machine learning techniques to perform systematic literature reviews.

Keywords: blockchain, food, digitization, supply chain, systematic literature review

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INTRODUCTION

Blockchain technologies (BT) have received increasing attention in supply chains over the past decade. As a decentralized peer-to-peer technology that maintains transactions within a distributed ledger system (Aldrighetti et al., 2021), BT is disruptive and offers valuable opportunities for actors across many industries, including the more general industry 4.0 (Hofmann et al., 2019); while becoming increasingly important within the food supply chain (Salah et al., 2019). Once touted as a digitally-based currency substitute (Tsang et al., 2019), the application of BT has burgeoned to challenge traditional business models. For instance, the food and beverage (F&B) industry has been viewed as an inefficient market due to its limited transparency, lack of transaction oversight, exposure to fraud, and authenticity concerns. For example, the horsemeat fraud scandal (Barnard & O'Connor, 2017) has affected grocery retail sales and consumer shopping patterns for meat consumption (Thornton, 2017). The industry has also been marred by transparency issues pertaining to seafood (Thornton, 2017), raising concerns over the authenticity of labels and the verification of claims (Brehaut, 2021). While in the beverages sector, unscrupulous actors have allowed the distribution of contaminated beer, causing human intoxication and death (Rodriguez, 2020). These examples demonstrate how the current system may leave reservations regarding the security, safety, and integrity of how F&B products flow through the supply chain.

BT provides numerous opportunities for constituents in the F&B industry. In contrast to traditional centralized systems (Park & Li, 2021), Zhang et al. (2021) suggest that security and transparency are guaranteed in BT using data decentralization. BT enables the sharing of information in real-time (Wang et al., 2021), whereby the inherent verification mechanism offers a peer-to-peer transaction system that is rooted in trust and visibility (Rogerson & Parry, 2020; Zhang et al., 2021).

BT offers the ability to record transactions across supply chain participants from raw materials to retail (Park & Li, 2021). It also shortens transaction times, improves accuracy, lowers execution risks, and increases system efficiency via a transparent ledger (Pinna & Ruttenberg, 2016). For instance, BT can be used to track data about transfers of shipment and handling at each stage of the F&B that may include information such as location, time, carrier and temperature details, etc. (e.g., Chakrabarti & Chaudhuri, 2017). Such information may provide track and trace data, thereby promoting the use of a secure and transparent information platform for stakeholders (Thakur & Breslin, 2020).

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As enterprise resource planning systems have furthered the requirements for ethical managerial oversight, the demands for traceability across F&B have gained traction among farmers, transporters, wholesalers, retailers, distributors, and consumers (Cao et al., 2021).

Further, BT creates governance value (Longo et al., 2020), extending beyond business boundaries (Cao et al., 2021). It is also an immutable information exchange providing risk reduction and assurances on provenance (Kamble et al., 2020; Longo et al., 2020). Feng et al. (2020) posit that research in BT has gained sustained momentum since 2017, with a particular focus on traceability. In part, a greater push toward the industry 4.0 era (Tsolakis et al., 2021) has intensified the need to track and trace the product journey along the supply chain (Kayikci et al., 2020). For instance, improved governance and viable regulatory frameworks have been insisted on by organizations such as "The EU Food Fraud Network" arising from scandals to prevent food fraud and assure regulatory compliance (Lin et al., 2019; Tan et al., 2020). For instance, in higher-value products such as honey (Jones Ritten et al., 2019) and extra virgin olive oil (La Pira, 2015), providing consumers with an assurance of origin, production and distribution are critical in building confidence in the product (Bimbo et al., 2019).

BT has the potential to enable better control of products, information, and financial flows. However, the process and technology on their own may not be sufficient (Fan et al., 2020) to ensure an efficient BT-based F&B supply chain system that is error-free. Moreover, much of what is known about BT has been theoretical (Stranieri et al., 2021), as the implementation of the technology has lagged behind an industry-broad process approach. As such, it is imperative to have a nuanced approach to determine the varied role that BT has in the F&B industry and its application. More specifically, the existing literature is synthesized with the goal of mapping out the landscape and influence of BT in the food industry to inform industry practitioners and researchers.

Going forward, a systematic literature review (SLR) is performed to uncover themes for exploration, diagnose links to practice, and identify directions for future research. The SLR approach provides a structured, objective, and replicable approach to reviewing the literature in comparison to a traditional approach that is susceptible to bias and is difficult to replicate (Kowalczyk & Truluck, 2013). The SLR approach in this study has been utilized in multiple fields, such as education, information technology, healthcare, and is appropriate due to its systematic scientific approach (e.g., Davies et al., 2013; Iden & Eikebrokk, 2013; Moraros et al., 2016; Zimmermann et al., 2016).

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Unique to this study, a state-of-the-art SLR method is deployed (i.e., machine learning) to minimize bias in the article selection process. This study proposes to address the following objectives:

a) identify primary and sub-themes of blockchain technology in the food supply chain literature;

b) discuss implications and applications in terms of delivering value;

c) propose literature-informed future research directions for the advancement of research in this research domain.

METHODOLOGY

In accordance with the best practices for conducting an effective systematic literature review (SLR; see Khan et al., 2003; Okoli, 2015; Siddaway, 2014; Xiao & Watson, 2019), goals and objectives are clearly identified as a guiding blueprint. Parameters for inclusion and exclusion of the literature are clearly established to provide replicable results. In addition, a machine learning technique is deployed as part of the selection process to minimize subjective errors. A thematic analysis is then conducted to classify and identify research trends and themes. Lastly, Watkins' (2017) Rigorous and Accelerated Data Reduction (RADaR) technique is utilized to examine the research gaps and investigate future research direction to provide literature-driven recommendations.

ARTICLE SELECTION

First, appropriate databases and keywords were identified based on a broad overview of the BT and F&B literature. Articles from Scopus and Web of Science (WoS) databases were extracted. These databases were selected due to access to high-quality papers and a complementary work set (Mongeon & Paul-Hus, 2016). In the databases, a keyword search was conducted in the title, abstract, and keywords with the following query "food AND traceability AND blockchain." The keywords were selected based on a literature overview coupled with industry expertise. Synder (2019) and Booth (2006) highlight the importance of identifying a specific and focused research discipline allowing for effective thematic findings and mapping of the focused field of research (see, e.g., Beske et al., 2014; Costa et al., 2018; Lim and Anthony, 2014). The initial search results returned 443 papers. The area of study was then filtered, including the following areas "Business/management/accounting AND social sciences AND Environmental science AND energy AND food science AND operations research management

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AND Engineering." This resulted in the exclusion of 190 papers. Journal articles were selected in "English," which resulted in a total of 42 papers being further excluded. After removing the duplicates, 106 papers remained.

Next, ASReview – an artificial intelligence software was trained and applied utilizing machine learning to further validate studies for relevancy in an objective and replicable way (Hindriks, 2020; Van de Schoot et al., 2020). The software uses the naïve Bayes approach, which is typically utilized for text classification of large datasets (Kadhim, 2019). The machine was initially trained via coding relevant and irrelevant papers. Then as the software generated a sufficient sample, it further delineated the relevant and irrelevant articles. In total, 37 articles were further excluded from this process.

In the end, the final sample included 69 papers. The exclusion process followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) to showcase the process of filtration and ensure adherence to the systematic approach (Moher et al., 2009). Table 1 outlines the step-by-step approach taken and provides clarity to the inclusion/exclusion criteria.

Table 1. PRISMA Checklist

Step	Number of articles	Action
1	Identified articles using Keywords from database (N=443)	Remove not relevant **excluded based on area of study** Business/management/accounting + social sciences + environmental science + energy + food science (WoS) + operations research management (WoS) + engineering (WoS) (N=190)
2	Remaining articles (N=253)	Remove not relevant excluded based on Language (English) and journal only (N=105)
3	Remaining articles (N=148)	Remove duplicates (N=42)
4	Remaining articles (N=106)	Relevancy check using Artificial intelligence (ASReview) (N=37)
5	Final sample (N=69)	

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Leximancer Analysis

The thematic analysis categorizes the collected literature into primary themes and sub-themes (Boyatzis, 1998), which allows for a detailed examination of the literature (Taylor & Taylor, 2009). As a precursor to the thematic analysis, a text mining software (Leximancer) is utilized to provide conceptual and relational maps using word occurrences and co-occurrences. The purpose of this analysis is to identify guiding categories in which the discovery of themes can be further interpreted. To conduct the Leximancer analysis (Leximancer, 2019), all papers were compiled by compressing the folder containing all 69 papers. Then filler words were removed, such as "and/or/if," using the "stop list" function. Following, additional unrelated words such as "figure/results/findings" were removed only to retain relevant words associated with the topic domain. As noted, Leximancer (2019) executes conceptual and relational analysis based on word frequency and occurrences. The analysis revealed four central concepts with 12 distinct concepts: a) adoption, b) transactions, c) products, and d) technology. The concepts are organized in relation to the proximity to each central concept: application, challenges, consumer, contracts, food, information, management, process, quality, safety, supply, and traceability.

Template Analysis

Next, we followed King's (2012) Template Analysis (TA) to thematically organize, analyze, and develop primary and sub-themes. TA is an inductive, iterative, structured and systematic technique that allows for the analytical process to evolve and adjust based on 'a priori knowledge' (developed via the Leximancer analysis). The stages of TA include: a) reading and familiarizing with the data; b) carrying out preliminary coding; c) developing the initial template utilizing the first template to make others; d) using the initial template to create iterative revisions coding other data; e) produce a final version of the template; f) use the final version of the template to interpret and map thinking and key findings around the topic; and, g) carry out quality checks at all stages as appropriate to fit the desired approach (King, 2012). The NVivo ™ software (NVivo) was used in the coding process. The digital files were introduced to the NVivo database, and cases were created for all 69 publications. In preparation for the coding process, the analysis revealed three primary themes and seven sub-themes.

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Following the thematic classification, the primary themes were examined in ascending order of repetition: a) **Transformation** (14 occurrences) refers to the proliferation of systems and stakeholder adoption (scalability; change management) across F&Bs; b) **Supply chain digitization** (53 occurrences) refers to the shifting of F&Bs activities from traditional centralized or manual systems towards decentralized integrated systems (track and trace; security and privacy), and c) **Value creation** (67 occurrences) refers to the generation of benefits for stakeholders including the ability to satisfy or surpass requirements in F&B flows (consumer sovereignty; quality; transparency), and enabling a demand-driven and democratized food chain. Figure 1 shows the distribution of primary themes across the collected literature.

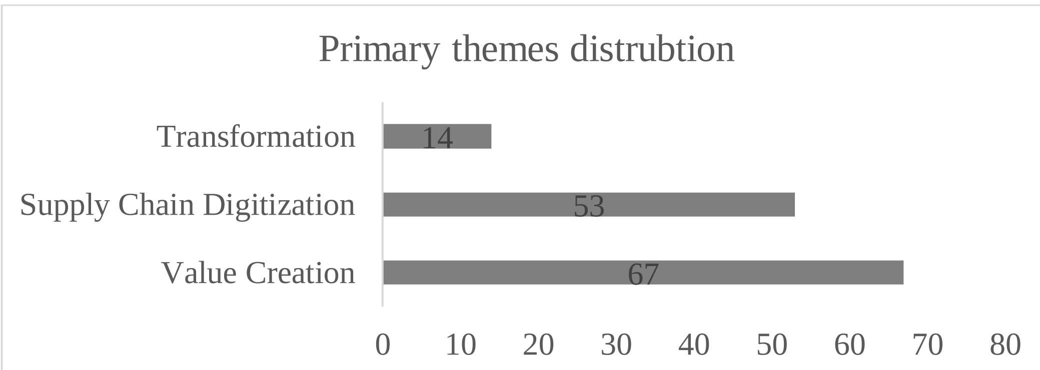

Figure 1. Distribution of primary themes

The primary themes were subsequently analyzed to examine the research impact based on the number of average citations that each publication has received to date. The average citations are calculated to demonstrate impact and relevance within the study. Supply chain digitization (mean=18.3), value creation (mean=17.11), and transformation (mean=16.85).

Following, emerging sub-themes were reviewed within the collected literature. The theme ‘transparency’ and ‘track and trace’ are present in most of the literature, having 48 and 47 occurrences, respectively. Transparency refers to the magnitude of information available to stakeholders based on the scale and scope of the various supply chain flows. Track and trace refer to the ability to follow transactions downstream ‘track’ or upstream ‘trace’ across F&Bs for a specific food product; together, it is commonly referenced as traceability.

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Scalability (4 occurrences) is least considered by the literature and refers to the enabling, expansion or contraction of systems either downstream or upstream along the F&Bs.

The remaining sub-themes in descending order of literature occurrences include 'quality' (37 occurrences), comprised of characteristics to satisfy stakeholders across the supply (e.g., consumers), including information, product, process, technology, and environmental conditions. "Change management" (12 occurrences) makes reference to the stakeholder change in perspectives, such as the willingness or resistance to switching from traditional systems in favour of newer technology. 'Consumer sovereignty' (11 occurrences) makes reference to the right of a consumer to exercise choice in the decision-making process. 'Security and privacy' (11 occurrences) make reference to the custody and protection of data resulting in the financial, logistical or information flows across the F&Bs that are accessible in private or public platforms.

RESULTS AND DISCUSSION

As noted, three primary themes were uncovered that exist within the collected literature: Value Creation, Supply Chain Digitization, and Transformation. The contents of each theme are discussed guided by the four Leximancer categories: a) adoption, b) transactions, c) products, and d) technology.

Value Creation

Adoption: Value cannot be realized until there is full adoption across the F&Bs. For instance, a non-participating actor within the F&B is likely to disrupt the flow of transparency that occurs within the supply network. Thus, value is only realized when parties agree on a system that allows for shared governance. Given that there are challenges associated with establishing trust with food retailers (Rampl, Eberhardt, Schutte, & Kenning, 2012), trust in technology, governance, and information access become of utmost importance for creating value (Kouhizadeh et al., 2021; Leduc et al., 2021; Rogerson & Parry, 2020).

Transactions

According to Giacalone et al. (2021), the capability of supply chain traceability pivots on demonstrating transparency in transactions. As an expectation, transparency increases with stringent requirements (e.g., regulation). Stranieri et al.

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(2021) suggest that transparency can be measured by accuracy, availability and degree of information shared across stakeholders. Collart and Canales (2021) suggest adopting a system that provides consumers with greater information transparency on credence attributes (i.e., product characteristics that cannot be verified after purchase or post-consumption). While some claim that BT offers data immutability (Collart & Canales, 2021), others argue that public data in BT is unlikely to gain value-add due to the lack of trust (Garrard & Fielke, 2020).

Products

As a precondition to consumer sovereignty, Garrard and Fielke (2020) posit that BT enhances access to product attribute information to promote consumer welfare. According to Machado et al. (2020), these characteristics may include efficacy, nutrition and safety information that can be shared with the consumer. According to Kumar et al. (2018), firms have struggled to implement BT technologies that provide effective product quality management. A major challenge is providing quality assurance guarantees (Shahbazi & Byun, 2021) while concurrently managing national and international regulatory requirements (Cao et al., 2021). This challenge is magnified when there is a greater distance between the upstream stakeholders and the consumer (Behnke & Janssen, 2020). Wang et al. (2019) propose the use of smart contracts for managing quality assurance. Behnke and Janssen (2020) posit that the exchange of quality assurance information between stakeholders should be at a detailed level, enabling verification of product attributes across process checkpoints (Aung & Chang, 2014) and reducing the level of bureaucracy along the supply chain flow (Aldrighetti et al., 2021). Garrard and Fielke (2020) posit that the value of BT should be benchmarked against other best alternative solutions. Value creation pivots on enhancing the consumers' visibility across F&Bs to determine the real-time status of product (Shew et al., 2021) and enabling transparency of information to assure product authenticity and legitimacy (Li & Wang, 2018 - 2018; Wang et al., 2019). Value creation is essential for improving customer service (Rogerson & Parry, 2020).

Technology

According to Casino et al. (2021) opportunities exist for increasing access and improving automated transmittal of compliant and non-compliant traceability information with regulatory authorities. BT has the potential to strengthen supply chain practice (Machado et al., 2020) and lessen negative impacts to society, the economy and environment (Aung & Chang, 2014) while driving competitive

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advantage (Ali et al., 2021) through strategic alliances in the supply network (Chen et al., 2020).

SUPPLY CHAIN DIGITIZATION

Adoption

Tsolakis et al. (2021) posit that supply networks require end-to-end integration and adoption in order to realize performance value from BT such as, enhancing visibility through digitization (Kharlamov & Parry, 2018). Sener et al. (2019) suggest that usage (behavioural adoption) rather than sharing of information enables performance gains that could benefit and have an impact on firm's financial resources.

Transactions

McConaghy et al. (2017) posit that visibility aids managerial decision-making while at the same time reducing the number of decision-making-points in the supply network by having accuracy and reliability of data exchanged (Stranieri et al., 2021). Giacalone et al. (2021) propose linking big data and BT as a security component to attain competitive advantage by digitizing the F&Bs. Digitization offers better track and trace capabilities while providing assurances on data security. The complexity of supply chains (Rogerson & Parry, 2020) may benefit from BT as a platform to provide assurance on data security and therefore data quality (Tian, 2016). Khan et al. (2020) and Lin (2019) have observed in their studies that BT increases data security, which contributes to building trust and securing data privacy with participants.

Products

According to Stranieri et al. (2021) traceability can vary across F&Bs dependent on regulatory requirements. Notably, traceability systems, via digitization of information, enable confidence in product quality and safety Fan et al. (2020). While several compliance and regulatory traceability factors are considered by the literature (e.g., atmospheric, environmental, see Giacalone et al., 2021; Westerlund et al., 2021), Giacalone et al. (2021) emphasize product provenance, product origin attributes that are exclusive to a geographical region. These types of information are often requested by consumers, a level of product transparency that BT can provide via digitization (Casado-Vara et al., 2018).

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Technology

While Kouhizadeh et al. (2021) outline technology as a barrier to transforming the supply chain, in private BT, Hao et al. (2020) stress the importance of visibility rights (Rogerson & Parry, 2020).

TRANSFORMATION

Adoption

Using a change management perspective, Kamble et al. (2020) posit that practitioners should lead stakeholders to overcome challenges. Benefits and improvements are possible in the area of production, finance, community (Kayikci et al., 2020), branding and certification (Garrard & Fielke, 2020), regulatory requirements (Yi et al., 2021) and consumer knowledge (Duan et al., 2017). Messer et al. (2017) advocate for closing the information gap between the upstream actors and the consumer for providing accurate information. Leduc et al. (2021) allude to the challenges in the F&B arising from power-shifts in relationships for firms operating under monopoly power, raising questions for custody of events that occurs across the supply chain flow. Thakur and Breslin (2020) posit that adoption challenges can pose scalability problems and while conceptual scalability solutions are offered, the literature could benefit from empirical cases from a change management perspective (Ali et al., 2021).

Transactions

Longo et al. (2020) posit that the food industry is reliant on physical documents with disjointed traceability. Hong et al. (2021) suggest data security and protection measures such as to prevent serialization theft are required (Thakur & Breslin, 2020). Thus, ensuring the integrity and confidentiality of the transactional data is necessary to promote consumer trust.

Products

Recently, BT partnerships have been introduced by large corporations in-part to improve quality and safety of food product through traceability. For example, in 2017, IBM collaborated with large industry partners in the food production and retail sector (e.g., Dole, Tyson Foods, Walmart, Lin, 2019). Kamble et al. (2020) posit concerns that originate from quality issues and the ability of economies to

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prevent losses and maintain food supply for populations. In response to global concerns, voluntary traceability systems were implemented by consumer-facing firms (Banterle & Stranieri, 2008). As these issues come to light, the competitive advantage borne from the uses of BT will enact a paradigm shift to the food industry.

Technology

Transforming the supply chain requires practitioners to focus on technology, processes and stakeholders. Kittipanya-ngam and Tan (2020) posit that a digital transformation can yield benefits of product quality and safety and product information traceability. Fan et al. (2020) argue that BT should record product information regarding its activities, characteristics and processes from the supply chain upstream to downstream flows (Tagarakis et al., 2021). As stakeholders realize benefits from digitizing supply chains, scalability of BT should extend across to all network participants regardless of size.

DIRECTIONS FOR FUTURE RESEARCH

Recommendations

Recommendations were developed by reviewing all 69-publications stated as per the article selection process. Watkins' (2017) Rigorous and Accelerated Data Reduction (RADaR) technique served to analyse and synthesise content systematically by: a) extracting future research directions; b) reducing data into short summaries; c) reducing summaries and amalgamate similar concepts; d) categorizing primary and sub-themes; and, e) documenting research deficits and trends, and f) relate the RADaR classification to the primary themes from the literature. Recommendations developed for each theme below, see table 2, are cross-references with categories to demonstrate the direction in which future research is based.

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Table 2: RADaR Approach for Future Research

Themes	Recommendations	Supporting References	Leximancer Categories
1.Value Creation	1a. Investigate the technological tools to achieve retail traceability in the FSCs	-Garaus and Treiblmaier (2021) -Machado et al. (2020) -Yu et al. (2020)	Technology
	1b. Explore the integration of all the firms that add value to a product or process	-Collart and Canales (2021) -Y. Wang et al. (2019)	Product
	1c. Examine the process of digitization of traditional SCs to enhance customer value	-Collart and Canales (2021) -Garrard and Fielke (2020) -George et al. (2019)	Transaction
2. Supply Chain Digitization	2a. Examine the implementation challenges of BT in the food chain and its long-term impact	-Niknejad et al. (2021) -Köhler and Pizzol (2020)	Adoption
	2b. Examine the mature BT models and their effectiveness in the industry to mitigate risk and expected serviceability in the SCs	-Westerlund et al. (2021) -Juan I.H.S. (2020)	Transactions
	2c. Explore the different uses of BT models across different industries	-Tayal et al. (2021) -Tsang et al. (2019)	Adoption
	2d. Explore the barriers to BT adoption	-Bumblauskas et al. (2020)	Adoption

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		-Etemadi et al. (2021) -Fan et al. (2020) -Hew et al. (2020)	
	2e. Evaluate BT adherence to data protection and privacy, while having reliable information transfer speeds and scalability across the SCs	-Chen et al. (2020) -Leduc et al. (2021) -Mangla et al. (2021) -Shahbazi and Byun (2021) -Shahid et al. (2020)	Transactions
	2f. Investigate solutions for reliable BT process that offer audit trails while ensuring rigour in practice	-L. Wang et al. (2021) -Hong et al. (2021)	Transactions
3. Trans-formation	3a. Conduct industry case studies to evaluate the technology for industry partners including the level of competitiveness in FSCs	-Giacalone et al. (2021)	Technology
	3b. Explore the different variables related to communication and responsibility of stakeholders in adopting newer technologies	-C. F. Lin (2019) -Tripoli and Schmidhuber (2020)	Adoption

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LIMITATIONS & IMPLICATIONS

There are several limitations to the SLR approach in this study. First, the publication selection criteria only selected publications from Scopus and Web of Science (WoS); any other publication not captured under the aforementioned scope, including non-peer-reviewed publications have been excluded. While this study seeks to be comprehensive, there may be articles that were not considered due to the filtering criteria. Second, the use of keywords to narrow the publication search criteria may have excluded publications that are relevant to the area of study. Third, by acknowledging the food industry focus in this publication, the research may be less applicable in practice to other industries. Fourth, while machine learning was used to derive themes as a means of verification against manual coding, the algorithms guiding the ASReview functionality were trained based on the researchers' interpretation. Thus, it is possible that biases could have shifted the order of importance in the range of the selected publications. To overcome this, two independent coders were trained to identify the included/excluded articles.

This study provides opportunities for BT compared to the existing traditional systems. Considerations should be given to a) the size of the F&B network and willingness to transmit data across F&Bs partners with the purpose of enabling greater visibility to the consumer; b) the distance of the F&B network and effects of regulatory requirements for maintaining compliant information flows; c) integration of traditional F&Bs activities and change management initiatives to support new technology, processes, and human resources; and d) potential risks from non-implementation of BT, including the firm's market competitive advantage.

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Declaration of Generative AI and AI-assisted Technologies

During the preparation of this work the authors used ASReview and Leximancer software in order to satisfy the relevancy of the literature and derive themes of interest. After using this software tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflict of Interest

The authors of this publication declare there is no conflict of interest.

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