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Digital Transformation in Food Supply Chains: An Implementation Framework

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Abstract

Purpose: Digital transformation utilising Industry 4.0 technologies can address various challenges in food supply chains (FSCs). However, the integration of emerging technologies to achieve digital transformation in FSCs is unclear. This study aims to establish how the digital transformation of FSCs can be achieved by adopting key technologies such as the Internet of Things (IoT), cloud computing (CC), and Big Data Analytics (BDA).

Design/methodology/approach: A systematic literature review (SLR) resulted in 57 articles from 2008 to 2022. Following descriptive and thematic analysis, a conceptual framework based on the Diffusion of Innovation (DOI) theory and the Context-Intervention-Mechanism-Outcome (CIMO) logic is established, along with avenues for future research.

Findings: The combination of DOI theory and CIMO logic provides the theoretical foundation for linking the general innovation process to the digital transformation process. A novel conceptual framework for achieving digital transformation in FSCs is developed from the initiation to implementation phases. Objectives and principles for digitally transforming food supply chains are identified for the initiation phase. A four-layer technology implementation architecture is developed for the implementation phase, facilitating multiple applications for FSC digital transformation.

Originality/value: The study contributes to the development of theory on digital transformation in FSCs and offers managerial guidelines for accelerating the growth of the food industry using key Industry 4.0 emerging technologies. The proposed framework brings clarity into the 'neglected' intermediate stage of data management between data collection and analysis. The study highlights the need for a balanced integration of IoT, CC, and BDA as key Industry 4.0 technologies to achieve digital transformation successfully.

Keywords: Food Supply Chain, Digital Transformation, Internet of Things, Cloud Computing, Big Data Analytics, Implementation Framework

1. Introduction

Food supply chains (FSCs) have recently become the focus of attention due to various global events such as Brexit, pandemic, and geo-political wars. The Russia-Ukraine war has widened the global supply gap while increasing international food prices (FAO 2022). Factors such as globalisation, growing world population, development of emerging technologies, trade agreements, rising consumer consciousness, climate change, and sustainability concerns significantly impact the food industry (Shukla and Jharkharia 2013; De and Singh 2021; Do et al. 2021; Ghadge et al. 2020c; Lerman et al. 2022). To cope with various challenges, food systems must be transformed through technological innovations (FAO 2021).

Industry 4.0 technologies are the enablers of digital transformation in FSCs to address multiple challenges, including food loss and waste (Annosi et al. 2021), poor standards for food safety and quality control (Mangla et al. 2018) and traceability issues with real-time transparency (Ben-Daya et al. 2019). Digital transformation has various interpretations in the academic literature. From an organisational standpoint, digital transformation can change the processes, operations, and products offered by the organisation (Sundaram et al. 2020). Hanelt et al. (2021, p.1187) define digital transformation as "*an organisational change triggered and shaped by the widespread diffusion of digital technology*". Digital transformation is also defined as "*a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies*" (Vial 2019, p. 118). Emerging technologies, including the Internet of Things (IoT), Cloud Computing (CC), Blockchain, Big Data Analytics (BDA) (including Machine Learning (ML), and Artificial Intelligence (AI)), are applied in various fields for addressing supply chain challenges (Ghadge et al. 2020a).

A practical framework for adopting digital transformation is needed to implement emerging technologies in FSCs successfully. A well-developed data management process can form the basis for adopting emerging technologies and developing new capabilities. Thus, in this study, different technologies of Industry 4.0 are selected to support the data management process to enable digital transformation in FSCs. Firstly, IoT systems (e.g., sensors, radio-frequency identification (RFID), cameras, scanners, etc.) are used to collect data and provide visibility of supply chain operations with real-time information. Similarly, BDA is regarded as a powerful tool for analysis including prediction, optimisation, and other decision-making. As the primary technology supporting connectivity, CC could provide diverse resources comprising software, platforms, and infrastructures for data storage and processing.

However, the transition from '*data collection*' to '*data analysis*' is generally neglected (Ben-Daya et al. 2019; Koot et al. 2021) and thus lacks in providing a holistic roadmap of digital transformation for practitioners. Furthermore, the research on digital transformation lacks empirical studies to verify contributions made by big data and analytical models, which leads to a low maturity level for such applications (Wang et al. 2016; Kamble et al. 2020; Lezoche et al. 2020; Annosi et al. 2021; Koot et al. 2021). This study focuses on IoT, CC, and BDA as equally important Industry 4.0 technologies to enable the digital transformation of FSCs. A comparison of literature reviews exploring the IoT, CC, BDA, and combined applications in FSCs is presented in Table 1. It is evident that literature lacks in bringing three unique technologies together to support digital transformation in FSCs. Compared to existing works, this study emphasises the equal importance of IoT, CC, and BDA, as well as their cohesive integration in enabling the digital transformation within FSCs.

Table 1*. A comparison of literature reviews on Industry 4.0 and food supply chains*

Literature reviews	**Digital transformation**	**Key technologies**			**Aim of study**
		IoT	**CC**	**BDA**	
This study	√	√	√	√	To provide a comprehensive view on enabling digital transformation in FSCs by adopting and integrating IoT, CC, and BDA in FSCs.
Lezoche et al. (2020)	√	√		√	To discuss how agriculture 4.0 helps to make better decisions in agri-food supply chains and impacts and challenges of different technologies, especially IoT and BDA.
Kamble et al. (2020)		√		√	To give a comprehensive view on achieving sustainability with IoT and BDA of a data-driven agricultural supply chain.
Nayal et al. (2021)		√		√	To find the missing links about integrated enabling technologies in the agricultural supply chain towards sustainability and circular economy.
Aamer et al. (2021)		√			To address the challenges of adopting IoT in the food supply chain.
Magalhães et al. (2019)		√			To identify the relationship between the frequency of publications on food supply chain traceability and the occurrence of food-borne disease outbreaks.

Literature reviews	Digital transformation	Key technologies			Aim of study
		IoT	CC	BDA	
Cappellesso and Thomé (2019)				√	To provide a view on technological innovation and food supply chain to synthesise and explore their interaction.
Thibaud et al. (2018)		√			To identify characteristics, challenges and possible solutions of IoT-based applications in high-risk industries, including food supply chains.
Weersink et al. (2018)				√	To examine the opportunities and challenges of big data in agriculture sector, including genomics, precision agriculture, and traceability in food supply chains.

Furthermore, several studies have been found to describe technology applications in FSCs. Most importantly, studies on Industry 4.0 do not address integration opportunities of emerging technologies or lack in offering approaches to achieve digital transformation in practice. To the best of the authors' knowledge, no relevant reviews or studies explore the parallel, integrative applications of IoT, CC, and BDA to enable digital transformation in FSCs. Thus, a systematic literature review (SLR) is conducted to provide a holistic perspective on how digital transformation can be enabled in the FSC with the support of IoT, CC, and BDA. The study sought answer to the following research question: *How do the Internet of Things (IoT), cloud computing (CC), and big data analytics (BDA) enable digital transformation in the food supply chains?* To address this research question, a concept map is first established to showcase how emerging technologies can facilitate the transition from traditional to digital supply chains. Later, with inputs from the literature review combined with diffusion of innovation (DOI) theory and the context-intervention-mechanism-outcome (CIMO) logic, a novel conceptual framework is proposed, specifically providing a comprehensive roadmap for achieving digital transformation in FSCs. This process-based roadmap shows systematic and easy-to-understand approaches (providing technical recommendations) to enable digital transformation in FSCs. Furthermore, several future research avenues are proposed based on the findings of thematic analysis and the insights gained from the proposed conceptual framework. This work brings together three key technologies to develop a conceptual framework for digital transformation in FSCs. The process-based roadmap is novel and anticipated to offer valuable guidance on implementing digital transformation within their supply chains.

The rest of the paper is organised as follows. Section 2 provides the research background on FSC challenges, digital transformation and theoretical lens. Section 3 demonstrates the methodology used to conduct the SLR. Sections 4 and 5 present the descriptive and thematic analyses, respectively. Section 6, the conceptual framework provides guidance for implementing digital transformation in FSCs and presents future research avenues. Finally, the paper concludes with a discussion, contributions, and limitations.

2. Research Background

2.1 Challenges in the food supply chain

Compared to other supply chains, FSCs are more complicated because of the perishable nature of products (Shukla and Jharkharia 2013), the requirement for higher flexibility and agility owing to the high variety of products and high frequency of orders (Viet et al. 2020), as well as increased customers' concerns about food safety (Mangla et al. 2018). Furthermore, FSCs face various challenges concerning increased food demand (Mogale et al. 2020), food quality (Irani et al. 2018), and sustainability (Mangla et al. 2018). Rising food demand and post-harvest losses significantly impact procurement and transportation, resulting in an imbalance between supply and demand and increased losses from food contamination and recall (Ghadge et al. 2017; Mogale et al. 2020). To ensure high service levels while keeping supply chain costs low, data-driven approaches for forecasting and transportation are used to ensure food freshness and balance supply with demand (Viet et al. 2020). Furthermore, information unavailability and low levels of collaboration among stakeholders could impede information sharing along the FSC, negatively affecting in terms of transparency, tracking and monitoring. Digital technologies are key to overcoming these fundamental FSC challenges (Annosi et al. 2021; FAO 2021). Emerging technologies, especially IoT, CC, and BDA, are expected to play a critical role in transforming traditional FSCs.

2.2 Digital transformation with IoT, CC and BDA

With the growing applications of Industry 4.0 technologies and their capabilities, digital transformation has captured the attention of researchers in the field of supply chain management. The transformation prompted by emerging technologies targets existing challenges and creates a positive impact on supply chain performance (Swierczek 2023; Lerman et al. 2022) through improved product quality, productivity, efficiency and sustainability (Corallo et al. 2023; Bourlakis and Weightman 2008).

The development and popularisation of shown infrastructure and equipment create a favourable environment for the integration of identified technologies (IoT, CC, and BDA) with existing organisational processes. With appropriate emerging technology support, data from different stages of the FSCs can be efficiently collected, processed, shared and analysed. IoT can be defined as "*an emerging global, internet-based information service architecture facilitating the exchange of goods in global supply chain networks*" (Weber, 2009, p. 522; Ancarani et al., 2020, p. 851), which is a fundamental technology of Industry 4.0 (Ben-Daya et al. 2019). With IoT, both humans and machines can communicate with the entities within or outside the supply chain (Ancarani et al. 2020). Big data analytics (BDA) is defined as "*a new generation of technologies and architectures, designed to economically extract value from huge volumes of a wide variety of data, by enabling high-velocity capture, discovery and/or analysis*" (Gantz and Reinsel 2011). The data transmitted by the IoT can be analysed using BDA tools and techniques to support decision-making (Chaudhuri et al. 2018).

Meanwhile, CC can be regarded as the bridge to connect IoT and BDA, and it is defined as "*the applications delivered as services over the Internet, and the hardware and software in the data centres that provide those services*" (Armbrust et al. 2010, p. 50). Compared to the other two technologies (IoT and BDA), there is relatively limited discussion on CC within SCs and FSCs in particular. Nevertheless, all three technologies are believed to be equally important, complementary, and must be carefully integrated to implement digital transformation in supply chains successfully.

2.3 Theoretical lens

The Diffusion of Innovation (DOI) Theory by Rogers (2003) is a robust theory that illustrates how new ideas, processes and emerging technologies are adopted and diffused by individuals or organisations. It has been used to explain how emerging technologies impact strategy and organisational change and illustrate the innovation process (Rogers 2003; Hanelt et al. 2021). Referring to the organisational innovation process, DOI introduces two main phases: initiation (agenda-setting, matching) and implementation (redesigning/restructuring, clarifying, routinising); the decision of adoption is between these phases (Rogers 2003). In the supply chain domain, DOI could serve as the foundation for implementing technological innovations; for instance, RFID adoption in the silk supply chain (Quetti et al. 2012) or Blockchain implementation for improving FSC performance (Wamba and Queiroz 2022; Vu et al. 2023). Furthermore, DOI can be used in conjunction with other theories aimed at different research objectives; for instance, it can be used with the technology-organisation-environment (TOE) framework to investigate the adoption process and technology diffusion in supply chain management (Xu et al. 2023).

To better illustrate the theoretical linkage between DOI as a general theory at the organisational level and the digital transformation process, middle-range theory (MRT) can serve as a foundation for potential connection to more general theories (Stank et al. 2017). MRT outlines the process of how to theorise at the middle range, which "*incorporates a level of specificity that restricts their explanation of causal connections to a subset of phenomena operating within a given domain*" (Stank et al. 2017, pp. 7; Merton 1968). In this research, the context-intervention-mechanism-outcome (CIMO) logic is applied to support the middle-range theorising approach, which provides the theoretical foundation of the digital transformation process (Hanelt et al. 2021). The CIMO logic demonstrates how mechanisms generate outcomes triggered by interventions within specific contexts (Stank et al. 2017; Denyer et al. 2008; Pawson and Tilley 1997). It is sufficiently generic to allow for widespread application in a variety of research settings. It is frequently used in the supply chain domain (e.g., Russo et al. 2021), as well as digital transformation and digital innovations (e.g., Hanelt et al. 2021; Henfridsson and Bygstad 2013). According to the CIMO logic, digital transformation can be analysed within specific contexts with interventions that trigger it, mechanisms for innovation and integration, and outcomes such as increased productivity and visibility (Hanelt et al. 2021; Denyer et al. 2008). The combination of the DOI and the CIMO logic builds the theoretical basis to connect the general innovation process with the digital transformation process.

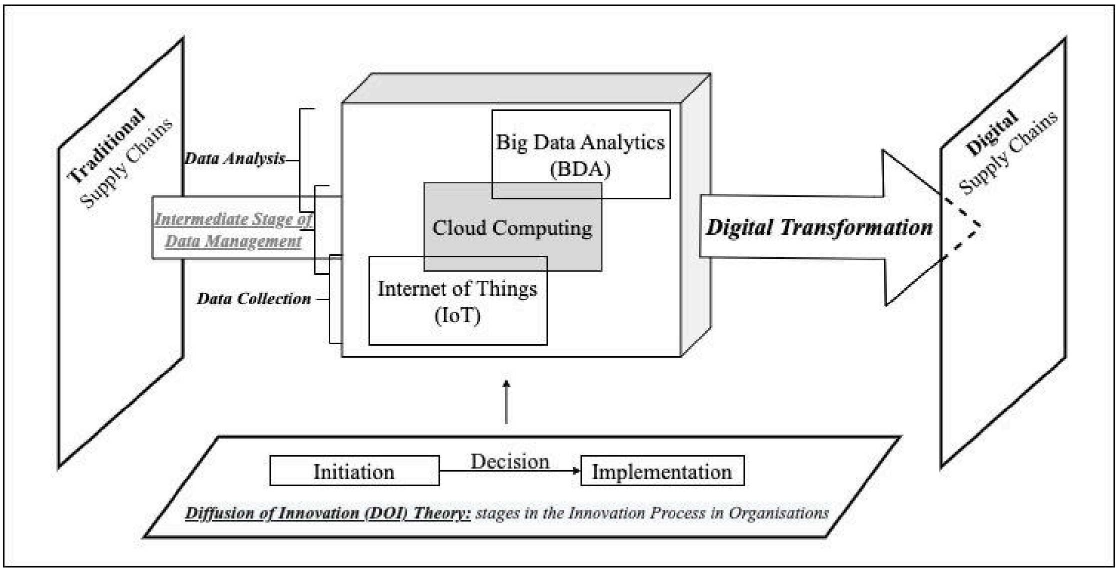

Figure 1. *The concept map of digital transformation in supply chains*

Above understanding of key Industry 4.0 technologies in overcoming supply chain challenges, along with the suitability of DOI theory (with CIMO logic) for implementation of innovation helps in constructing a 'concept map' (Figure 1). This concept map depicts the conceptualised innovation process for transitioning from traditional to digital supply chains. With inherent advantages fully exploited, these three technologies are expected to support the digital transformation of FSCs by covering the entire data management process.

3. Research Methodology

A systematic literature review (SLR) provides a comprehensive, unbiased, and evidence-based search (Tranfield et al. 2003). In contrast to a traditional literature review, an SLR answers a specific and clear review question and informs future research (Denyer and Tranfield 2009). Based on the three stages of SLR by Tranfield et al. (2003) and additional text-mining steps provided by Ghadge et al. (2012), Figure 2 presents the adopted SLR process followed in this paper.

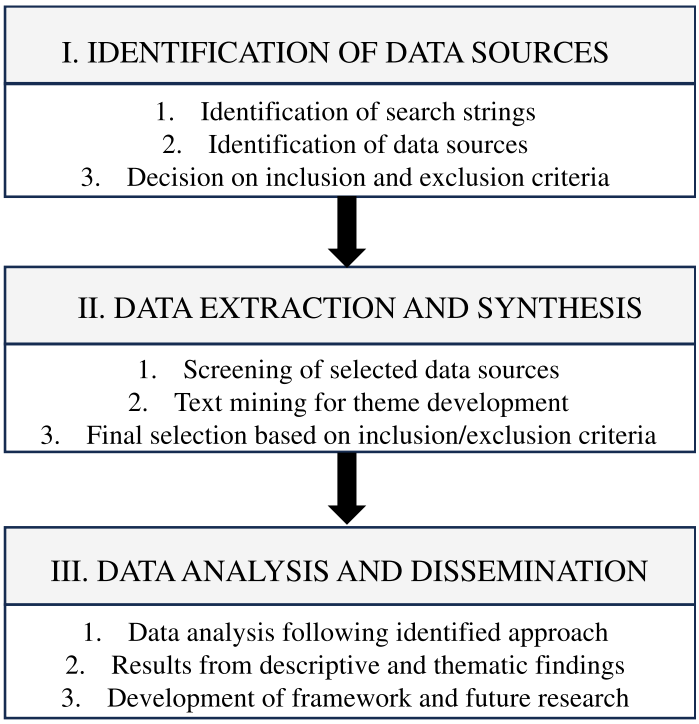

Figure 2*. Systematic literature review process*

(Adopted from Tranfield et al. 2003 and Ghadge et al. 2012)

Identification of Data Sources

The review begins by identifying databases, keywords, time horizons, and search strategy. The time range selected for this research is from 2008 to 2022 since the IoT is a fundamental technology of Industry 4.0, which first appeared between 2008 and 2009 (Evans 2011). Furthermore, when searching for IoT, CC, and BDA separately in the supply chain literature with no time limit, the relevant articles published on IoT and CC started to appear in 2008, which aligns with the emergence of IoT. Scopus, Web of Science (WoS), ABI/INFORM, and Business Source Complete (EBSCO) were selected as the databases for a comprehensive literature search.

The most used keywords were identified and filtered to locate those that are highly relevant to the research. However, some narrow or unique terms, such as 'Internet of Manufacturing Things' or 'Prescriptive Analytics', were not considered. Also, AI and ML were not considered separately since they fall within the broad field of BDA. Following keyword sorting, corresponding individual and combined search strings were finalised (Table 2). Then, the search strategy was devised based on the research question to guarantee that the results supported and derived useful inferences to develop a conceptual framework and future research directions.

***Table 2**. Keywords with search strings and search strategy for SLR*

Industry 4.0 technologies	**Applied field of study**
S1: Internet of Things *("Internet of Things" OR "IoT" OR "Internet of Pre/4 things")*	**S4: Food supply chain** *("food supply chain" OR "food value chain" OR "FSC" OR "Agr?-food" OR "Agr?food" OR "Agr?-fresh" OR "AFSC" OR "Agricultur* supply chain" OR "perish* food" OR "cold chain" OR "chilled food")*
S2: Cloud computing *("cloud-computing" OR "cloud comput*")*	
S3: Big Data Analytics *("big data analy*" OR "BDA" OR "big data")*	

Later, inclusion and exclusion criteria were defined to include only English publications. In addition, document types were restricted to articles published in the academic journals. While practitioner journals, conference proceedings, books, book chapters, and other grey literature (e.g., newspapers, white papers, HTML links, etc.) were excluded. This exclusion of the '*grey literature*' in SLR studies helps to focus on high-quality work (Seuring and Müller 2008; Ghadge et al. 2012).

Data extraction and synthesis

The second stage is determining the final set of articles and conducting descriptive and thematic analysis. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram with four phases is adapted to present the literature selection process (Page et al. 2021).

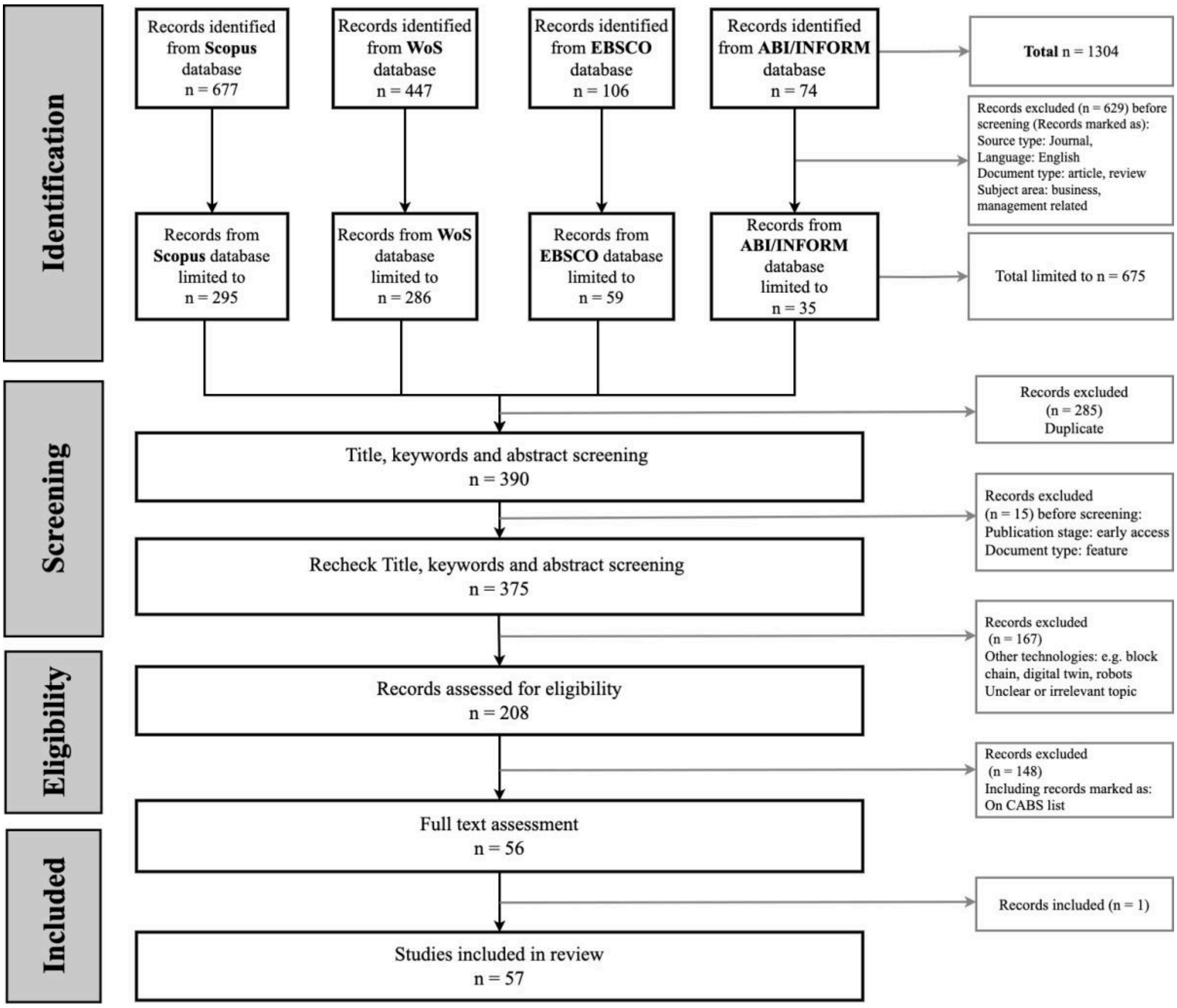

Figure 3. *PRISMA flow diagram of the systematic literature review*

As shown in Figure 3, the identification phase is the initial round of searching, employing defined inclusion and exclusion criteria. Then, the screening phase seeks to eliminate duplicates and narrow the literature pool using additional exclusion criteria. Articles irrelevant to the research were excluded during the abstract screening process; for example, publications purely focussing on technologies such as Blockchain, robotics, and Augmented Reality were excluded. Moreover, in the eligibility checking phase of the PRISMA (refer to Figure 3), the selected articles were further assessed with a specific relevance check and quality assessment criteria. Data quality must be evaluated to ensure reliability and improve confidence in the analysis results (Tranfield et al. 2003; Durach et al. 2017), especially concerning the methodology, implications for practice, and overall contributions of the FSC studies. Finally, following a detailed screening process, 57 articles were selected to form the SLR review pool.

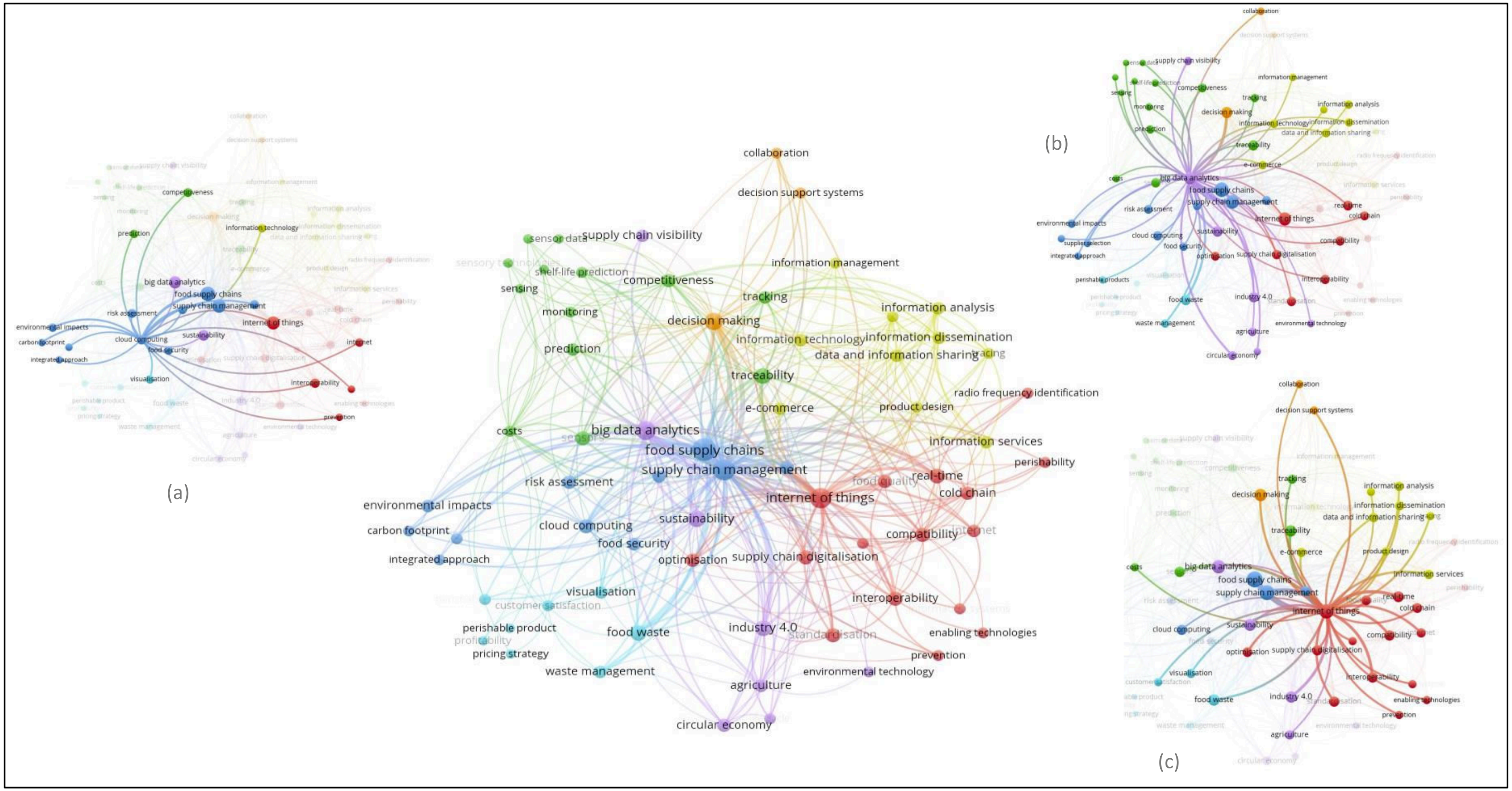

__Figure 4.__ Cluster diagram of selected articles

Data analysis and dissemination

Emerging themes were identified using the text-mining approach. Text mining of selected articles was conducted to validate the search strings identified in the first stage and provide further support for theme development (Ghadge et al. 2020b). Figure 4 presents the cluster diagram of selected articles showcasing important clusters. Smaller clusters around show key linkages associated with (a) cloud computing, (b) Big data analytics and (c) Internet of Things. These clusters were utilised to cross-validate the choice of keywords/search strings and identify themes for thematic analysis. It is evident that all three technologies have strong links with each other as well as (food) supply chains. The reporting and dissemination stage comprises descriptive and thematic analysis (Tranfield et al. 2003). The results of the descriptive and thematic analyses are presented in this section. The outcome of this analysis is a conceptual framework and future research directions.

4. Descriptive Analysis

The descriptive analysis highlights the general state of the developments in digital transformation in FSCs utilising IoT, CC, and BDA technologies. Figure 5(a) presents the year-wise distribution and applied research methodologies in the selected studies. It is evident that the research interest in digital transformation is growing, with mixed methodology as the preferred adoption approach, as shown in Figure 5(b). Table 3 presents theories, approaches, and models used. An overview of different combinations of the three technologies (IoT, CC, and BDA) is presented.

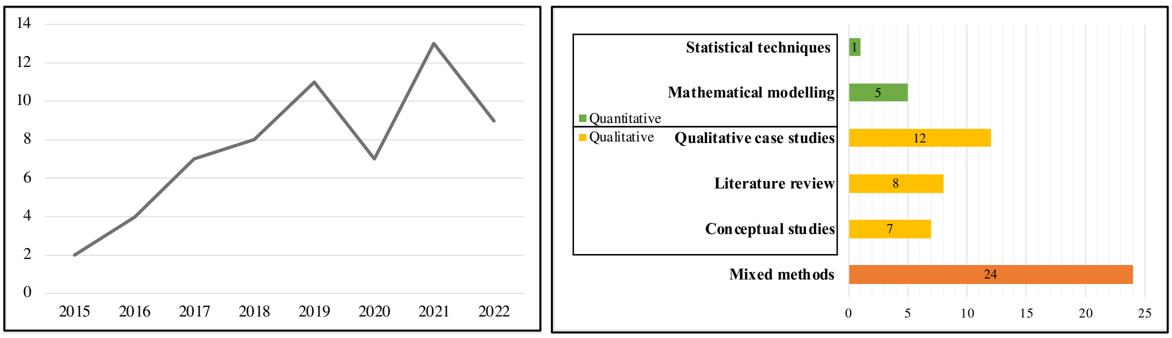

***Figure 5(a)**. Year-wise distribution; **Figure 5(b)**. Adopted research methodologies*

Table 3. *Use of theories, approaches and models*

Category	References	Applied theories, approaches or models
Theories (19.3%)	Shang et al. (2015)	Design theory for building an IoT-based general reference architecture.
	Bogataj et al. (2017)	Extended material requirements planning (EMRP) theory.
	Zhang et al. (2017)	Industrial organisation theory for exploring the industrial agglomeration phenomenon of perishable food supply chain.
	Singh et al. (2018a); Tsang et al. (2018); Coppolino et al. (2020)	Fuzzy set theory for supplier selection, occupational safety risk assessment in the cold chain, and selection of cloud services.
	Ali et al. (2019)	Grey system theory (GST) for dealing with uncertainty in human or objective judgment.
	Irfan and Wang (2019)	Information processing theory (IPT).
	Yadav et al. (2020b)	Stakeholder theory derived from the resource-based view (RBV) and institutional theory.
	Yadav et al. (2022)	Dynamic capability theory (DCT).
Approaches or models (31.6%)	Verdouw et al. (2015)	Integrated product, process and manufacturing system development (IPPMD) reference model.
	Singh et al. (2015); Belaud et al. (2019)	Life cycle assessment (LCA).
	Li et al. (2017); Tsang et al. (2020)	Service-oriented architecture (SOA) for IoT implementation.
	Singh et al. (2018a)	Decision making trial and evaluation laboratory (DEMATEL) method
	Kaur (2019)	Fuzzy total interpretive structural modelling (Fuzzy-TISM).
	Kappelman and Sinha (2021)	Generalised Markov Decision Process (MDP) model for describing the decision-making process in the food supply chain.
	Kazancoglu et al. (2021)	Interpretive structural modelling (ISM) is used to identify the relationships between various drivers or enablers.
Other (38.6%)		Literature review (14%); Self-developed framework or approaches (12.3%); Interview-based studies (7%); Technology-based studies (3.5%); and strategy (1.8%).
Not specified (7%)		Without specific theories, approaches, models, frameworks, or other categories mentioned above.

Table 3 shows the diverse set of applications of theories and approaches followed for digital transformation in FSCs. Studies illustrating theoretical foundations focus on developing an architecture for IoT implementation (e.g., Shang et al. 2015; Li et al. 2017; Tsang et al. 2020), identifying drivers or factors affecting the use of specific technologies in the FSCs and the relationships between them, along with analysing scenarios with specific research topics.

Among the management theories, resource-based view (RBV) theory and dynamic capability theory (DCT) have been used as the foundation of relevant studies multiple times.

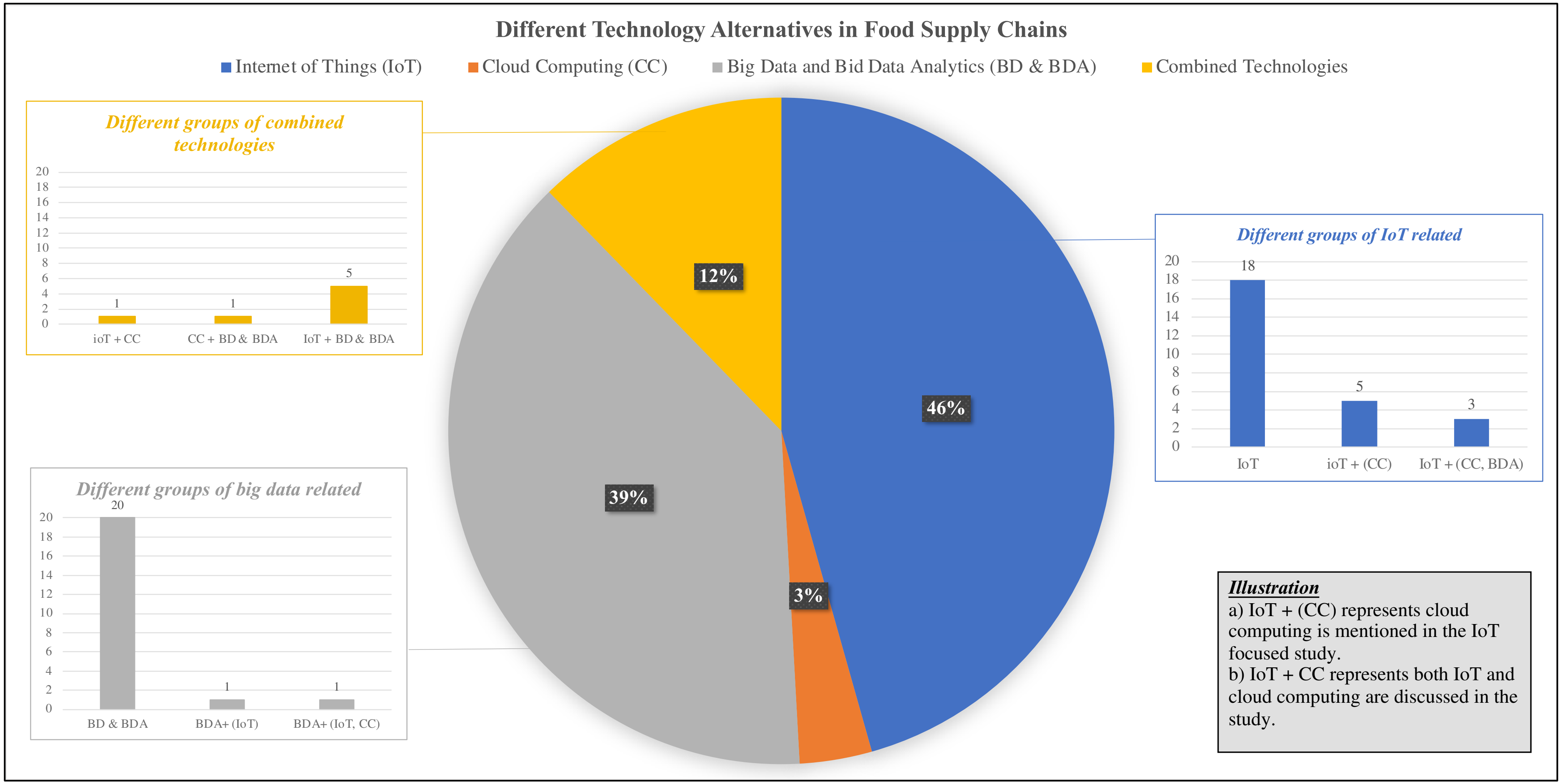

***Figure 6**. The overview of different technology combinations in FSCs*

The fuzzy set theory is frequently used to support the analysis after applying emerging technologies, but it is not directly related to the process of enabling digital transformation. It is evident that there is a lack of established theory for implementing digital transformation, particularly in the context of FSCs.

The three underlying technologies in the FSC can be applied independently or in combination. Figure 6 depicts the utilisation of various technologies. Regardless of the individual deployments or combinations, the relevant studies mostly focus on the IoT and BD/BDA. Conversely, CC is infrequent and, at times, independently investigated and appears as a supporting function in IoT-based research. Furthermore, limited studies combine them and emphasise their equal importance. Interestingly, no study considers all three emerging technologies together for digital transformation in supply chain context. These insights help to strengthen the identified research gap and the need for this study.

5. Thematic Analysis

Thematic analysis is developed based on the identified typologies presented in Figure 7. First, the authors identified different potential themes derived from text-mining and the preliminary review of articles on digital transformation interfacing supply chains. Following the CIMO logic and after multiple brainstorming activities between authors, key typologies were finalised, comprising key FSC objectives, principles enabling digital transformation, technology implementation architecture, and SC analytics solutions.

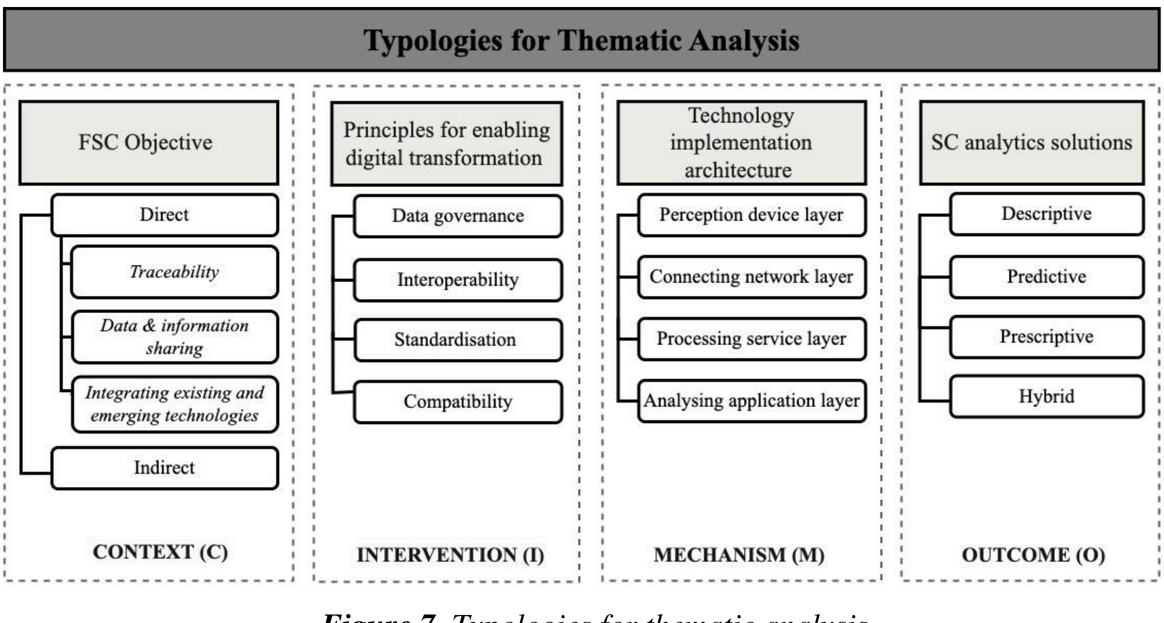

Figure 7. *Typologies for thematic analysis*

5.1 Main objectives of digitally transformed food supply chains

To realise the transformation from traditional FSC to digital FSC by applying Industry 4.0 technologies, the initiation stage in the innovation implementation process requires the expectations and objectives to be identified (Rogers 2003). Several subjects are regarded as hotspots by practitioners and researchers for continuous exploration and application in FSCs, which form different specific contexts (C) and are expected to be achieved directly and indirectly by digital transformation in the FSC.

Direct FSC objectives

The direct objectives consist of traceability, data and information sharing, and integrating existing and emerging technologies, which will further benefit the indirect objectives.

Traceability

Traceability is one of the most discussed research topics in the FSC, with an increasing number of studies applying the IoT as a core technology for capturing real-time information. Real-time traceability has gained much attention and could influence the time interval captured by the corresponding information system (Kayikci et al. 2022; Li et al. 2017; Tsang et al. 2018; Verdouw et al. 2015). With shorter time interval data capture capability ideal for real-time feedback and information, monitoring and tracking of food products can become more effective (Magalhães et al. 2019). The need for and realisation of traceability could have multifaceted impacts on various challenges in the FSC. The internal drivers for food traceability are value and efficiency, and the external drivers are safety and quality, sustainability, and consumer satisfaction (Latino et al. 2022). Traceability enabled by IoT in the cold chain helps determine potential interventions for in-transit products to ensure food quality and safety (Nayal et al. 2021; Rendon-Benavides et al. 2022). Sustainability targets can be achieved using different information and communications technologies, including IoT, while improving food quality and traceability (Nayal et al. 2021). Notably, traceability linked to information sharing using IoT is a growing area of interest, where CC is used as a supporting capability providing the ability to store and share the data collected by the IoT.

Data and information sharing

The emerging technologies of Industry 4.0 and the trend towards digital transformation have allowed innovations to move away from being centralised in one organisation and dispersed throughout the entire FSC (Cappellesso and Thomé 2019; Yan et al. 2016). As a result, information can be exchanged and shared between diverse and decentralised sectors of FSCs (Yan et al. 2016). The utilisation of both IoT and CC creates more possibilities for sharing data/information. For instance, real-time information sharing is supposed to be realised through a cloud service platform to ensure the food safety of fruits and vegetables (Zhang et al. 2017). Similarly, the rapid exchange of real-time information is of the highest significance for supply chain responsiveness, which increases flexibility and resilience and enhances adaptability (Yadav et al. 2020b). Data and information sharing is necessary for FSCs, since it could be facilitated for reducing food wastage and improving performance (Kayikci et al. 2022). Furthermore, data/information sharing could be closely linked to traceability, addressing issues such as food security, safety, and waste (Moysiadis et al. 2022).

Integrating existing and emerging technologies

Issues related to integrating existing and emerging technologies and their implementation have earned good attention within the field of digital transformation (Hanelt et al. 2021). For instance, a food chain visibility platform may use an existing enterprise resource system but wishes to integrate data analytics capabilities (Shang et al. 2015). However, linking the new platforms to the already established platforms has been challenging and needs further work in technology integration (Kayikci et al. 2022; Shang et al. 2015; Tsang et al. 2018). For example, for smart packaging in the cold-FSC, QR codes or barcodes are fundamental information carriers (Kayikci et al. 2022), but they also need to link with temperature and moisture sensors along with Global Positioning System (GPS) devices (part of the IoT). To address these challenges, at the stage of IoT implementation, the FSC stakeholders need to spend more time and effort on understanding the related SC problems and needs (Beker et al. 2016; Kazancoglu et al. 2021).

Indirect FSC objectives

Indirect objectives include food waste and loss, food safety and integrity, competitiveness, and environmental impacts. They could be reached only by achieving the direct objectives discussed above. For instance, food integrity can be managed by integrating IoT and BDA (Irani et al. 2018). In fact, the issue of food integrity, combining the concerns of food safety, authenticity, and quality, is probably due to the lack of alignment of common objectives and standards among multiple independent stakeholders, which could be regarded as a lack of synergies and collaboration (Donaldson 2022). Supply chain visibility is defined by Barratt and Oke (2007, p.1218) as *"the extent to which actors within a supply chain have access to or share information which they consider key or useful to their operations and which they consider will be of mutual benefit."* Visibility is key to developing data analytics capabilities and improving FSC performance (Kamble et al. 2020; Yadav et al. 2020a; Rengarajan et al. 2022). Food safety in the cold chain can be monitored during the production, process, transportation, storage, and sale by establishing a visibility platform with IoT, CC, and BDA (Shang et al. 2015).

Furthermore, integrating emerging technologies can positively influence a company's competitiveness (Tsang et al. 2020). For instance, using big data in the FSC is viewed as a source of competitive advantage due to data-driven analytical capabilities (Irfan and Wang 2019). Larger companies usually have more competitive advantages, since they own more available data, IT infrastructure, skilled resources, and disposable investments (Annosi et al. 2021), which might lead to an imbalance of knowledge and power when compared to SMEs (O'Connor and Kelly 2017; Battistoni et al. 2023). However, larger companies could be more sensitive to technological risks, such as cyber security and trust issues between different actors in supply chains (Singh et al. 2015; Annosi et al. 2021; Ghadge et al. 2020b). On the other hand, for SMEs, especially start-ups, it might be easier for them to apply cloud technologies using software as a service (SaaS). Generally, larger enterprises can utilise big data and advanced technologies in their business to assist in taking market share; hence, it is hard for smaller organisations to get involved and get close to customers and profits (O'Connor and Kelly 2017; Weersink et al. 2018). Nevertheless, it is necessary for SMEs to apply Industry 4.0 technologies, which can provide support and confidence as well as minimise risks associated with decision-making. Furthermore, using advanced technologies can efficiently help deal with sustainability issues and strengthen resilience in FSCs (Singh et al. 2015; Stone and Rahimifard 2018).

5.2 Principles enabling digital transformation in food supply chains

Prior to implementing innovation, critical principles enabling digital transformation in SCs can be set as interventions (I) to invoke mechanisms (Beker et al. 2016; Denyer et al. 2008). The review identified four critical principles, comprising of data governance, interoperability, standardisation, and compatibility.

Data governance

Data governance is broader than data management as it covers not only data collection, processing (including transmission, storage, and sharing), and data analysis, but also data accuracy and security (Weersink et al. 2018; Thibaud et al. 2018).

Availability and usability

It is crucial to effectively achieve the expectation of using emerging technologies in various FSCs, which is not only about the data itself that needs to be available, but also about how to better utilise that data. For example, sometimes food companies own the sensors that produce real-time data, but they might lack the ability to further transmit/share and analyse these data (Tsang et al. 2018). Moreover, wireless sensors or GPS data are used primarily for cold chain monitoring or tracking (Luo et al. 2016). This data could be later used for prediction and decision-making in FSCs.

Interpretation and analysis capability

Analytics capability is essential for transferring the data into useful information in supply chains (Kamble et al. 2020). With various algorithms and methods, BDA could be used for interpreting large volumes of data generated by the IoT (Yadav et al. 2020a). However, there is a shortage of data analytics applications within FSCs (Mondragon et al. 2020). It also underlines the idea that various data analytics tools and techniques are needed to overcome different FSC challenges.

Data and information accuracy

For data-driven supply chains, precise data is essential for building resilience and robustness by reducing uncertainties and risks (Lezoche et al. 2020). BDA is welcomed in new food product development, but it doesn't mean the larger volume of data equals better analysis and results (Jagtap and Duong 2019). The quality of the information generated after deriving and processing data must be accurate and make sense.

Security and safety

Data privacy and security aspects apply while utilising emerging technologies from Industry 4.0. The ownership of the data, access control, data authentication, and client privacy protection are double-edged swords (Aamer et al. 2021; Moysiadis et al. 2022; Weersink et al. 2018). Data privacy plays an important role, especially in public cloud or hybrid cloud applications.

A data authorisation mechanism is needed to share the data or information only with authorised stakeholders within the FSC (Li et al. 2017; Moysiadis et al. 2022). For instance, the data generated from a real-time tracking and tracing platform for FSCs captures consumers' IP addresses (Li et al. 2017), which might cause privacy issues such as personal geolocation leaks. Moreover, data privacy, cyber security, and business confidentiality should be considered before deploying new technologies (Kaur 2019; Ghadge et al. 2020b).

Interoperability

Interoperability is frequently mentioned in studies related to the use of technologies in FSCs, which can be understood as the ability of computer systems or software to exchange and make use of information (Thibaud et al. 2018; Frederico et al. 2020; Latino et al. 2022; Moysiadis et al. 2022). From a macro perspective, interoperability can be seen as the coordination or collaboration among different actors in the FSC. On the other hand, from a micro perspective, interoperability is needed for stakeholders' information systems to communicate and share data in the FSC in line with governance principles and regulations (Thibaud et al. 2018; Weersink et al. 2018). Developing new technologies and considering their interoperability are necessary to fully exploit the data (Lezoche et al. 2020). Data can be exchanged between different technologies, and each of them could make use of it. Therefore, such communication is bidirectional. For instance, interoperability can be enhanced by connecting physical and virtual objects on an IoT-based supply chain risk monitoring system (Tsang et al. 2018). The cloud plays a vital role in storing and analysing information. However, interoperability could increase the communication complexity between sensors, as they need a univocal language of standards along the entire supply chain (Latino et al. 2022; Jagtap et al. 2021).

Standardisation

Only a few studies discuss the specific communication standards in FSCs. Even though a huge amount of heterogeneous data is collected in the FSC, poor integration of intelligence obtained from such data is still an unaddressed issue (Thibaud et al. 2018). As for an IoT-driven system to reduce food waste, standardisation and smart contracts are mostly needed but are largely ignored (Jagtap and Duong 2019; Kaur 2019). Standardisation has an inseparable relationship with interoperability (Thibaud et al. 2018; Aamer et al. 2021). Specifically, it is important to have the standard syntax and semantics of interoperability, which are fundamental to information exchange (Latino et al. 2022). For example, the interoperability standard chosen to ensure the external traceability of the olive oil supply chain was the EPC (electronic product code), a common standard followed globally to uniquely identify any physical entity (Latino et al. 2022).

Compatibility

Compatibility concerns in the digital transformation of FSCs could be divided into three types: (1) sensors between themselves or different stakeholders; (2) sensors and networks; and (3) intra- and inter-systems. For sensors and networks, differences between the devices in the IoT are influenced by the complexity of FSC networks (Shang et al. 2015). Hence, a single protocol can't support the entire IoT or CC system in FSCs due to the heterogeneous networks. Intra-system compatibility refers to the ability of a newly developed system to successfully connect to local or existing systems. In contrast, inter-system compatibility refers to the smooth communication of different systems by FSC's internal and external stakeholders (Irfan and Wang 2019). Interestingly, the problem of intra-system compatibility with existing systems is rarely discussed (Moysiadis et al. 2022; Tsang et al. 2018; Zhang et al. 2017).

5.3 Technology implementation in food supply chains

The scalable and flexible technology implementation architecture as mechanism (M) assists in forming different solutions for different stages of FSCs. Based on the reference of different architectures summarised in Appendix, a generic implementation architecture is adapted and conceptualised considering the characteristics and functions of the IoT, CC, and BDA. This four-layer architecture comprises the perception device layer, connecting network layer, processing service layer, and analysing application layer.

Perception device layer

The perception device layer aims to generate and collect data from physical devices like sensors and infrastructures of connectivity. Therefore, the basic elements of the perception device layer could be the interconnection of different 'things', including sensing technologies, RFID tags and readers, and transmitting technologies like GPS (Attaran 2007; Yadav et al. 2020b). The detailed choices of tools used in the perception device layer, which include different types of IoT (including wireless sensing network (WSN) devices) to enable digital transformation in FSCs are shown in Table 4.

The IoT devices in the perception device layer address challenges like traceability, food safety and quality and are particularly beneficial in perishable FSCs. Sensors are the core of the perception device layer. Therefore, a systematic portfolio of sensors is needed to build a perception device layer (Pang et al. 2015). After understanding the types and functions of various sensing tools, an intelligent tracking system should be developed to effectively monitor products in real-time using IoT (Luo et al. 2016). Large volumes of sensor data collected through IoT devices can be regarded as the big data, which is critical for resource optimisation in FSCs (Ciccullo et al. 2022; Pang et al. 2015).

Connecting network layer

The core objective of the connecting network layer is data transmission, which includes wireless and wired networks and transmission protocols. The data/information can be transferred between sensor nodes or to the next processing service layer, for instance, to the cloud. The typical technology used in this layer is a wireless sensor network (WSN). While CC acts as a supporting system for the connecting network layer, it also plays a role as a bridge linking data collection and data transmission. According to various applications in FSCs, different ranges of wireless networks could be selected, as shown in Table 5, comprising short-, medium-, and long-range wireless networks and the wired network to support transmission tasks.

The connecting network layer builds on the basis of the perception device layer to transmit information about food products across supply chains. As a result, FSC stakeholders are able to select better solutions with a diverse range of wireless or wired network choices. For instance, the traceability of different kinds of FSCs can be realised with medium- and long-range wireless networks.

Processing service layer

The processing service layer relies on the cloud for further data processing and sharing, including service providers as well as communication protocols and standards for information sharing. CC is the conventional technology in the processing service layer and supports information sharing. However, it is rarely mentioned as one of the important capabilities in the literature. Nevertheless, CC is widely used in FSCs, which is demonstrated with detailed applications in Table 6.

Table 4. *Summary of the perception device layer with applications in FSCs (Representative Technology: IoT)*

Category I	Category II	Possible choices	Objectives	Food supply chain stages*	Reference
Sensing devices: sensors	Environmental sensor	• Temperature • Humidity • Soil moisture • Pressure • Water, air quality • CO2, O2, Ethylene • Vibration, shock, tilt • Light	Food safety	Entire fruit and vegetables supply chain	Pang et al. (2015); Tsang et al. (2017); Latino et al. (2022)
			Food quality	Deliver in the food cold chain	
			Traceability	Entire raw material food supply chain	
General devices	Location sensors	With GPS	Food safety	Entire fruit and vegetables supply chain	Pang et al. (2015)
	Fundamental and identification devices	• RFID Tags and readers • Scanners • Actuator • QR Code • EPC code • Bar codes • Sensor tag cc2650	Technology innovation	Deliver in the fruit and vegetables supply chain	Verdouw et al. (2015); Luo et al. (2016); Li et al. (2017); Tsang et al. (2018, 2020))
			Traceability	Deliver in the food cold chain	
				Entire processed food supply chain	
			Food safety and quality	Entire food cold chain	
				Deliver in the perishable food supply chain	
				Entire perishable food supply chain	
	Wireless sensing network (WSN) physical devices	• Zigbee router • Bluetooth devices	Traceability	Deliver in the food cold chain	Luo et al. (2016); Jagtap et al. (2021)
			Food waste	Make in the food supply chain	
	Other	• GPS (Global Positioning System) modules (e.g. GPS antenna) • Cameras, Closed-circuit television (CCTV)	Food safety	Entire fruit and vegetables supply chain	Pang et al. (2015); Jagtap et al. (2021)
			Food waste	Make in the food supply chain	

**SCOR Model is applied to describe FSC stages, including plan, make, source, deliver, and return* (Bolstorff and Rosenbaum 2003).

***Table 5**. Summary of the connecting network layer with applications in FSCs (Representative Technology: Wireless sensor network (WSN))*

Category I	Category II	Possible choices	Objectives	Food supply chain stages*	Reference
Wireless and wired network	Short-range wireless	• Bluetooth • NFC • RFID • Wi-Fi • Zigbee	Food quality	Deliver in the food cold chain	Tsang et al. (2017, 2020); Miranda et al. (2019); Jagtap et al. (2021); Moysiadis et al. (2022)
				Deliver in the perishable food supply chain	
			Technology innovation	Entire food supply chain	
			Food waste	Make in the food supply chain	
			Information sharing	Entire crop supply chain	
	Medium-range wireless	• Mobile telecommunication networks 2G/3G/4G/LTE • 5G	Traceability	Entire cold food chain	Luo et al. (2016); Latino et al. (2022); Tsang et al. (2020)
				Entire raw material food supply chain	
			Food quality and safety	Deliver in the perishable food supply chain	
	Long-range wireless	• LPWAN, e.g. LoRa wan	Traceability	Entire seafood supply chain Entire raw material food supply chain	Mondragon et al. (2020); Latino et al. (2022)
	Wired	• Ethernet • USB	Technology innovation	Entire food supply chain	Miranda et al. (2019)
Transmission protocols	-	• M2M transmission protocols • TCP/IP • MQTT (Message Queuing Telemetry Transport) • CoAP (Constrained application protocol)	Food safety and quality	Entire food cold chain	Tsang et al. (2018, 2020); Jagtap et al. (2021)
				Deliver in the perishable food supply chain	
			Food waste	Make in the food supply chain	

**SCOR Model is applied to describe FSC stages, including plan, make, source, deliver, and return* (Bolstorff and Rosenbaum 2003).

To select a suitable cloud service for FSCs, first it is necessary to ensure that the cloud has the required functions (Tsang et al. 2020). Then, according to three basic cloud service models, including SaaS (software as a service), PaaS (platform as a service), and IaaS (infrastructure as a service); a suitable service should be decided in line with the FSC applications following different objectives and capabilities of stakeholders. For instance, IaaS is chosen for agri-food manufacturing/processing because it creates an elastic infrastructure and provides good solutions for resource workload fluctuations (Coppolino et al. 2020). SaaS (Software as a Service) cloud computing delivery models can be deployed by small or medium-sized companies using a private cloud (Singh et al. 2015). In recent years, the '*as a service*' (_aaS) paradigm, or XaaS, has received much attention. However, the details of utilising the cloud are still unclear, and more questions have risen about coordination between entities when using the cloud. Furthermore, the sharing standard and the common semantic format are two important components in the processing service layer for exchanging and sharing data and information. Two data sharing standards when exploring the traceability in the FSC include GS1, UK as a widely known standard for barcodes and EPCIS (electronic product code information service), which are critical to interoperability by reducing the variation in business operations through the use of standard vocabulary (Moysiadis et al. 2022).

Analysing application layer

The analysing application layer aims to provide various analyses and decision support in FSCs, where BDA as the underlying technology can be fully exploited. In practice, the configuration for the analysing application layer in FSCs is flexible and more oriented to actual problems that need to be solved. User interface (UI) aims to display the analysing application layer with different interfaces for system software users. For instance, in food manufacturing, UI design with web services, mobile and desktop applications can perform visualisation and reporting using descriptive and diagnostic analytics for monitoring and alerts (Jagtap et al. 2021). The detailed summary of components constructing the analysing application layer and the corresponding application in different types of FSCs is shown in Table 7.

Different algorithms and methods can support BDA to perform a range of analyses based on the support of the previous three layers. For example, the vehicle routing problem (VRP) in e-commerce logistics for perishable products (Tsang et al. 2020) and location-allocation problems in the cold chain (Singh et al. 2018b) are typical optimisation problems solved using prescriptive analytics. Although many studies investigated big data applications, most of them still focused on the data and ignored the analytics. Furthermore, there is a lack of integrated multi-algorithm insight to address different challenges simultaneously in the diverse stages of the FSC.

5.4 Different level of solutions at various stages of food supply chains

Following the assessment of selected studies, FSC solutions as generated outcomes (O) with the application of IoT, CC, and BDA can be divided into four types based on the different types of big data analytics (Delen and Zolbanin 2018): (1) descriptive (including diagnostic); (2) predictive; (3) prescriptive; and (4) hybrid solutions.

The IoT largely supports reporting and visualisation and focuses on addressing direct objectives like tracking and monitoring supported by descriptive analytics. Solutions with prescriptive and hybrid approaches on the other hand, tend to use combined technologies with a focus on indirect objectives in various sectors of FSC, especially to ensure food quality and safety. IoT is utilised by logistics service providers, supply chain managers, and decision makers, who are mostly concerned with deliveries and the operation of the entire FSC (Tsang et al. 2017, 2020; Zhang et al. 2017). BDA plays an important analytic role with IoT and CC to assist decision-making and strategy provision for different stakeholders in FSCs, for instance, for abattoirs or processors to cut down on emissions (Singh et al. 2018a) and retailers to reduce food waste (Kayikci et al. 2022).

However, it is rare to see the predictive solution as an independent approach used in FSC alongside IoT, CC, and BDA. For instance, rice yield can be predicted by utilising spatial data, including geographical information (Esfandabadi et al. 2022). In summary, typical FSC applications using BDA are summarised in Table 8.

Table 6. Summary of the processing service layer with applications in FSCs (Representative Technology: Cloud Computing)

Category I	Category II	Possible choices	Objectives	Food supply chain stages*	Reference
Services provider	Cloud database (dynamic and static data)	• Cloud APIs (Microsoft, IBM, AMS) • PaaS	Technology innovation	Deliver in the fruit and vegetables supply chain	Verdouw et al., (2015); Tsang et al. (2017, 2018, 2020); Jagtap et al. (2021); Latino et al. (2022)
			Food safety and quality	Deliver in the food cold chain	
				Entire food cold chain	
				Deliver in the perishable food supply chain	
			Food waste	Make in the food supply chain	
			Traceability	Entire raw material food supply chain	
	Everything as a service (XaaS)	-	Food safety	Entire fruit and vegetables supply chain	Pang et al. (2015)
	SQL	• MySQL5.5.12 • SQL server 2008	Food safety	Entire fruit and vegetables supply chain	Pang et al. (2015; Luo et al. (2016); Yan et al. (2016)
			Traceability	Deliver in the food cold chain	
			Information sharing	Entire meat supply chain	
	GIS data provider (Geo-spatial services)		Technology innovation	Deliver in the fruit and vegetables supply chain	Verdouw et al. (2015)
Data sharing and exchange	Common data format & Semantic	• JSON (JavaScript Object Notation) • XML (Extensible Markup Language) • PML (Physical Markup Language) format which is based on XML • HTML • CBV (Core Business Vocabulary)	Information sharing	Entire meat supply chain	Yan et al. (2016); Moysiadis et al. (2022); Li et al. (2017); Tsang et al. (2017, 2018, 2020)
				Entire crop supply chain	
			Traceability	Entire processed food supply chain	
			Food safety and quality	Deliver in the food cold chain	
				Entire food cold chain	
				Deliver in the perishable food supply chain	

Standard	• EPC standard • GS1 standard • EPCIS standard: EPC information services (EPCIS) System By inquiring through object name service (ONS) and ALE (application-level events)	Information sharing	Entire meat supply chain	Yan et al. (2016); Moysiadis et al. (2022); Latino et al. (2022)
			Entire crop supply chain	
		Traceability	Entire raw material food supply chain	

**SCOR Model is applied to describe FSC stages, including plan, make, source, deliver, and return* (Bolstorff and Rosenbaum 2003).

Table 7. *Summary of the analysing application layer with applications in FSCs (Representative Technology: BDA)*

Category I	Possible choices	Objectives	Food supply chain stages*	Reference
Front-end web development	• HTML5 • JavaScript • CSS3 • 3D-GIS, GPRS-GIS • UI design: mobile app, desktop app, web service	Food safety and quality	Entire fruit and vegetables supply chain	Pang et al. (2015); Tsang et al. (2020); Weersink et al. (2018); Jagtap et al. (2021)
			Deliver in the perishable food supply chain	
		Technology innovation	Deliver in the fruit and vegetables supply chain	
		Food waste	Make in the food supply chain	
Algorithm deployment	• Python programming	Food safety and quality	Deliver in the perishable food supply chain	Tsang et al. (2020)
Back-end development	• PHP • Asynchronous JavaScript and XML (AJAX)	Food safety and quality	Entire fruit and vegetables supply chain	Pang et al. (2015); Tsang et al. (2020)
			Deliver in the perishable food supply chain	

**SCOR Model is applied to describe FSC stages, including plan, make, source, deliver, and return* (Bolstorff and Rosenbaum 2003)

Table 8. *Pilot applications with different level of food supply chain analytics solutions*

FSC analytics solutions	Specific tools	Pilot application	Description	Reference
Descriptive	Reporting, visualisation	Extra virgin olive oil (EVOO)	It aims to test the framework for traceability and provide communication solutions to the consumers with visualisation modules in the olive oil supply chain supported by IoT.	Latino et al. (2022)
		The Internet of Food and Farm (IoF2020)	It aims to demonstrate traceability and how existing data sharing standards can be applied in crop supply chains supported by IoT, especially for pre-harvest activities in a case study about table olives.	Moysiadis et al. (2022)
Predictive	Prediction, data mining	Paddy rice yield	It uses satellite-based data with GIS (Geographic Information System) support and proposes a suitable index for rice yield prediction.	Shams Esfandabadi et al. (2022)
Prescriptive	Guidance/strategy support	Crops sourcing: banana, cocoa beans and barley	It provides guidance on current and future suitability of diverse types of crops for sourcing in different countries based on the climate change data.	Srinivasan et al. (2019)
	Decision making, optimisation	Valorisation of the rice straw supply chain	It aims to provide decision support on agricultural waste valorisation and manage the environmental impacts supported by big data.	Belaud et al. (2019)
	Simulation, guidance/strategy support	Bulk apple sales	It tests the dynamic pricing strategy to reduce food waste at retailers in simulated scenarios with the support of IoT and BDA.	Kayikci et al. (2022)
Hybrid	Visualisation, prediction	SmartAtlantic	It performs predictive analysis with visualisation, which assists in identifying trends and patterns of snow crab capturing, supported by the IoT and BDA.	Mondragon et al. (2020)

	Reporting, visualisation, decision making	IoT-based risk monitoring system (IoTRMS)	It aims to monitor the ambient environment of products and provide occupational safety risk management in frozen and fresh food supply chain supported by IoT.	Tsang et al. (2018)
	Reporting, visualisation, optimisation	IoT-based FEW decision-support tools	It aims to track and monitor food waste, energy and water consumption (FEW). It provides a decision-making process to improve resource efficiency in food manufacturing.	Singh et al. (2015)
	Reporting, visualisation, guidance/strategy providing	SaaS for Carbon Calculation	It applies SaaS cloud computing service to measure carbon emissions and provides feedback at the farm end of the beef supply chain.	Jagtap et al. (2021)
		IoT-based cargo monitoring system (IoT-CMS)	It aims to provide the storage guidance according to the real-time data from sensors in the cold chain.	Tsang et al. (2017)
	Reporting, visualisation, prediction, optimisation	Field test of Royalsweet Brazilian melon	It provides a hierarchical information fusion architecture (HIFA) with shelf-life prediction, cost assessment, and real-time supply chain re-planning for decision making supported by IoT and GIS.	Pang et al. (2015)

6. Conceptual Framework and Future Research

Following descriptive and thematic analysis and adopting the DOI theory along with the CIMO logic, a conceptual framework for implementing digital transformation in FSCs is developed (Figure 8). Furthermore, insights generated from thematic analysis and the proposed conceptual framework are used to develop future avenues for research.

6.1 Conceptual framework for implementing digital transformation in FSCs

Based on the DOI theory and the CIMO logic, a novel conceptual framework is developed with four different levels to enable digital transformation in FSCs (Figure 8). This is established based on the concept map of digital transformation in supply chains presented earlier in Figure 1.

The innovation process of DOI provides the general theoretical basis for implementing digital transformation since emerging digital technologies are regarded as innovative practices that can shift and reshape traditional organisations and industries (Hinings et al. 2018). To link the general theory level with the digital transformation, CIMO logic builds the connection at the middle-range level, targeting the specific context in FSCs. Subsequently, the digital transformation process emphasises the transition brought about by applying emerging technologies that are different from traditional information technology (Hanelt et al. 2021). As shown in Figure 8, four levels direct the transition from theory to practice. Beginning at the bottom left, it first depicts how technological innovations can be linked with digital transformation.

The core of the conceptual framework at the process-based level shows how key Industry 4.0 technologies can enable digital transformation and further help to answer the research question conclusively. Aligning with the initial phase of the innovation process, the FSC objectives (shaping the specific contexts) and key principles for enabling digital transformation (as essential interventions) are in the role of information gathering, identifying expectations/needs, and foreseeing the feasibility of innovation. Subsequently, the technology implementation architecture, as the main mechanism triggered by those key principles, serves as the foundation for generating outcomes and forming tailored solutions during the implementation phase in the digital transformation process.

The *'typology-driven'* process-based roadmap begins with a focus on the direct and indirect objectives of FSCs. Many of the challenges researchers and practitioners focus on for FSCs are indirect. However, the first step in addressing issues such as food waste or food safety and achieving strategic goal of supply chain sustainability and/or resilience is to take the lead in addressing direct objectives. The key principles can be regarded as guidelines to tackle the issues to be solved, which play important roles in activating the following technology implementation architecture. The most fundamental principle is data governance, and only after data is guaranteed can interoperability, standardisation, and compatibility be considered.

After identifying the business problem and the motivation for digital transformation, the adoption decision is made in the innovation process (Rogers 2003). The proposed four-layer technology implementation architecture is then applied (as part of the process-based roadmap) to identify suitable Industry 4.0 technologies and their fit in the FSC context. The architecture comprehensively covers multiple tools and techniques from fundamental technologies. Meanwhile, the intermediate stage of the data management process is clearly presented in the informative toolkit within four different layers. In addition, representative technologies for each layer discussed in detail play a critical role in supporting digital transformation and providing concrete guidance for researchers and practitioners.

The last step of this process-based roadmap is to form tailored solutions with help of flexible layer configuration and availability of abundant data. Different solutions can be formed depending on the extent of the use of data/information, which can range from low to high depending on the sophistication of the solution(s). The most basic functions are reporting and visualisation; however, and as the complexity increases, there is a greater demand for analysing data using predictive and prescriptive analytics tools such as optimisation, simulation and decision support system.

Finally, different generated solutions to various FSC problems support managers in making robust decisions at the application level. The solutions to various problems in FSC functions are appropriately addressed using an integrated approach by combining IoT, CC, and BDA together. Through the successful application of these emerging technologies in FSCs, the implementation phase (part of the innovation process) provides routinisation, that will gradually become a regular part of digitally transformed FSCs. It is evident that the benefits of implementing digital transformation can be observed across the wider FSC network.

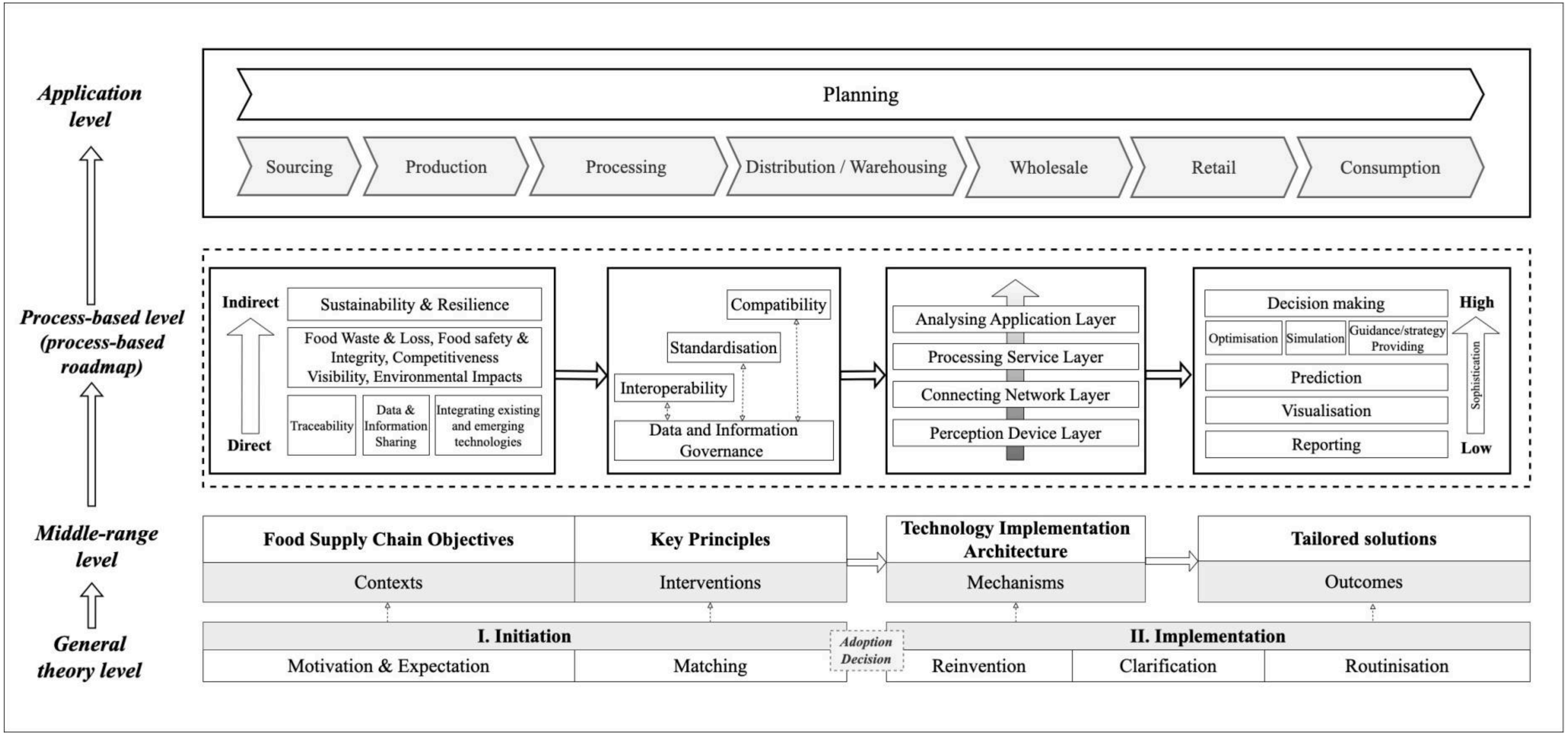

***Figure 8**. Conceptual framework for Implementing digital transformation in FSCs*

6.2 Future Research Avenues

The following research directions are identified based on key inferences drawn from thematic analysis and the proposed conceptual framework.

- ***Maturity model for digital transformation in FSCs***

The adoption of integrated Industry 4.0 technologies in FSCs is still at a nascent stage (Kamble et al. 2020; Yadav et al. 2020a). To test the proposed conceptual framework, further empirical studies are required to validate and measure supply chain performance. It is also important to gain a clear vision from different stakeholders in the food industry about their present technological state to guide digital transformation. Maturity models can be used to assess the status quo and provide directions or guidelines for improvement (Caiado et al. 2021). The overall maturity level requires more research to examine technological realisation. Therefore, how to identify the maturity level of emerging integrated technologies in supply chains, what factors could impact the maturity level and their relationships, how to build the maturity model for digital transformation and how to enhance the maturity level of implemented technological solutions are some of the unanswered research questions.

- ***Human perspective of implementing digital transformation in FSCs***

In this study, the developed conceptual framework captures the technological perspective. However, multiple barriers to implementing emerging technologies exist from the human perspective, such as involvement of various stakeholders, including security issues for data and information exchange and the accessibility of relevant skills (Latino et al. 2022; Aamer et al. 2021). Cost of investment concerns include a longer payback period and higher cost of deploying new technology (Li and Wang 2017; Thibaud et al. 2018). Thus, further research is needed to understand the attitudes of different sizes of companies towards the long payback. Furthermore, particular skills needed to utilise emerging technologies might influence job creation and destruction (Balsmeier and Woerter 2019). Therefore, studies focussing on the social perspective related to digital transformation are necessary to capture a holistic understanding of implementation challenges associated with digital transformation in supply chains.

- ***Integration with wider systems and technologies for Digital transformation***

New technology implementation needs to be compatible with existing systems and technologies in the FSC. The complexity of introducing new technology into existing platforms and importing data from old systems is still a challenge (Tsang et al. 2020; Zhang et al. 2017), and there is a lack of approaches to connect them seamlessly. Therefore, integrating new technologies and existing systems needs further investigation (Lezoche et al. 2020). Furthermore, IoT, CC, and BDA are the three foundational technologies that pave the way for increased technological integration, algorithmic applications, and analytical diversity. However, it is evident from the thematic analysis that integration with other supporting technologies can add significant value. Hybrid technologies such as cloud-based GIS that is used for visualisation and spatial analysis (Bogataj et al. 2017; Luo et al. 2016; Accorsi et al. 2018; Kamble et al. 2020); AI/ML combined with VR (virtual reality) are used for cognitive decisions in autonomous systems; Blockchain could play an important role in information sharing and data security (Ghadge et al. 2023), ensuring secure, immutable records and a single version of truth. Therefore, the utilisation of other technologies as potential solutions can target existing technical problems.

- ***Cyber security and safety issues in the digital transformation***

IoT, CC, and BDA connects with wider networks and data systems. While accessing these technologies, the issue of cyber security remains a concern, particularly with the use of CC. Data security issues arise when FSC stakeholders share critical information through third-party platforms (Jagtap and Duong 2019; Ghadge et al. 2020b; Creazza et al. 2022), which are highlighted in the thematic analysis as a key principle to take into consideration from the beginning of the digital transformation process. Currently, homomorphic encryption allows data to be computed and shared in an encrypted format in the cloud (Alloghani et al. 2019). However, the increased number of cyber-attacks in supply chains requires wider solutions, such as the use of Blockchain or other encryption capabilities. Furthermore, the trade-off between data privacy for all FSC participants and the benefits gained from information exchange among relevant stakeholders' merits reconsideration.

- ***Clarity on influential factors in 'adoption decision' for digital transformation***

Two main phases (initiation and implementation) are extensively discussed in the proposed conceptual framework; however, the intermediate phase of the '*adoption decision'* is critical and thus requires more attention, particularly in terms of which factors influence the adoption decision-making. Technology, organisational, and environmental factors dictate adoption decisions according to Vu et al. (2023). From a technology perspective, the integration of hardware, software, networks and cybersecurity measures needs to be reassuring. Commitment and vision from senior management, along with skilled and engaging employees will boost confidence while making such decisions. Furthermore, intertwined environmental factors such as industry characteristics, customer demands, government regulations, support, and compliance are other extrinsic considerations (van Dun and Kumar, 2023; Tornatzky and Fleischer, 1990). Influences of the above factors on adoption decision need focused assessment.

- ***Potential of digital transformation in SMEs***

Smaller stakeholders, such as small farmers and small- and medium-sized enterprises (SMEs), require more attention as an important component of the agri-food supply chain. The size of firms is relevant to the resource availability for the investment in IoT and BDA (Rengarajan et al. 2022). SMEs face challenges in terms of competitiveness compared to larger enterprises that tend to dominate market share and have abundant resources. Further research is needed to address limitations and challenges in implementing technologies with small stakeholders, including capability and willingness to invest in technological infrastructure (Tsang et al. 2018; Weersink et al. 2018); lack of professional knowledge and training (Weersink et al. 2018; Annosi et al. 2021); and capability of data utilisation, analytics, and management (O'Connor and Kelly 2017).

- ***Alternate theoretical lenses for realising digital transformation***

The stages of the innovation process adopted from the DOI theory and the CIMO framework serve as the theoretical foundation for this research. However, adopting alternate theories or approaches by supply chain researchers could shed new light. For example, the technology acceptance model (TAM) and its extension, the unified theory of acceptance and use of technology (UTAUT) (Davis 1989; Venkatesh et al. 2003), may bring understanding in terms of user acceptance and behavioural intentions (effort and performance expectancy) while implementing digital transformation in FSCs. Furthermore, the core of the proposed conceptual framework is process-based, which depicts how utilisation and integration of key technologies can enable digital transformation in FSCs. Future research can explore the adoption of the above-suggested theories and associate them with process/operations management to draw additional insights towards building literature on digital transformation.

7. Conclusion, Contributions and Limitations

7.1 Conclusion

This study provided a comprehensive overview of the digital transformation in FSCs, enabled by fundamental technologies including IoT, CC and BDA. Following the SLR process, Integration of IoT, CC, and BDA is emphasised with equal importance to fill the research gap in addressing integration opportunities of emerging technologies in the entire data management process. By screening all selected articles, the descriptive analysis provided a general picture of preferences referring to the utilisation status of different technology combinations in food industries and diversely utilised theories, models, or approaches to support relevant applications. The novel conceptual framework based on the DOI theory and the CIMO logic is developed following the thematic analysis of different typologies. Direct and indirect objectives of FSCs and key principles to transform supply chains digitally are identified in the initial phase of the process. Subsequently, the implementation phase follows a four-layer technology implementation architecture, resulting in various analytical solutions for FSC. The breakdown of the innovation process provides theoretical instruction on how to utilise the framework in practice. Overall, the added value of the proposed conceptual framework is its guidance to achieve digital transformation in FSCs through the integration of IoT, CC, and BDA. Finally, seven future avenues are outlined to expedite the research in digital transformation for SCM.

The digital transformation of FSCs has become an area of increasing interest, but it is still slow compared to other fields (Kamble et al. 2020). Thus, the requirements of commonly accepted theory, integrated technology solutions, and the involvement of different stakeholders are highlighted to enhance the implementation of digital transformation in FSCs. With a growing trend towards utilising emerging technologies for FSCs, a commonly accepted theory is necessary while implementing digital transformation. This study provided insights into adopting the DOI theory and CIMO logic together to shape the digital transformation implementation process at the organisational level. The MRT provides the basis for further empirical studies to be conducted. Meanwhile, there is potential to consider other innovative or cross-discipline theories that could benefit from implementing digital transformation in FSCs.

7.2 Contributions to theory

This review provides contributions to theory as well as practice. First, to the authors' best knowledge, it is the first SLR focused on how digital transformation can be realised in FSCs. It theoretically contributes to emphasising the integration of IoT, CC, and BDA. The SLR also brings clarity to the intermediate stage of data management between data collection and analysis. The study also explains the significance of IoT, CC, and BDA as equally important Industry 4.0 technologies and capabilities.

Furthermore, the proposed conceptual framework provides insights into the relationship between the innovation and digital transformation process based on the combined use of the DOI theory and the CIMO logic, helping to connect emerging digital technologies at an organisational level. Simultaneously, it brings together critical typologies and provides holistic guidelines for the implementation of digital transformation in FSCs. In particular, the study captures the challenges in FSCs and categorises them into direct and indirect objectives that can be addressed sequentially. The key principles are summarised, and data governance is highlighted as the foundation of technical capabilities throughout the data management process.

As a core section of the novel framework, the process-based roadmap systematically utilised IoT, CC, and BDA as representatives manifested in the technology implementation architecture with four different layers. The unified name of these four layers and generalisation of the main functions of layers enable scholars to utilise them easily. The architecture also highlights the unique characteristics of these three fundamental technologies to cover the entire data management process. It also provides a clear and detailed view for academics to follow the implementation process from data collection to data analytics. Within each layer, technical portfolios provide the details to target different FSC challenges with various applications. Supply chain researchers can gain valuable insights from the implementation framework to discover alternate theories aligning with technology implementation in supply chain contexts. Ultimately, the study suggests future avenues that will require further empirical research to test the conceptual framework for implementing digital transformation in FSCs.

7.3 Contributions to practice

The review contributes to practice by providing insights into the transition from conventional to digital FSCs. This study makes the digital transformation process systematic and easy to understand and apply for SC practitioners. Managers in the food industry can gain insights into drivers and barriers to a successful implementation. The study also raises awareness about technology issues associated with data governance, interpretability, standardisation, and compatibility. Furthermore, insights into multiple applications of BDA capability for FSCs will help managers invest in analytical platforms for making informed decisions.

Different FSC stakeholders can utilise the insights generated in this study to physically test the capability of selected technologies (and associated tools) to achieve digital transformation within their organisations. In addition, the study inspires the food industry to digitalise their SC operations utilising Industry 4.0 technologies. Furthermore, the findings can assist policymakers in establishing relative standards or rules, which could encourage more stakeholders to accept selected emerging technologies. The establishment of the overall process-based roadmap, particularly critical principles in the initiation phase, could provide directions for policymakers to develop relative conditions or incentives, especially for the SMEs (EIB Economics Department 2023). Finally, the detailed technology portfolio could assist in setting standards for establishing necessary digital infrastructures by government and policy makers (GOV.UK. 2022).

7.4 Limitations

There are some limitations to this study. The review pool included only 57 high-quality journal articles published between 2008 and 2022. The authors' bias for interpretation may have occurred due to the limitations of the number of articles but is reduced by involving cross-checking from other co-authors. Text mining was used to cluster and validate the choice of keywords; however its use was limited. Digital transformation applications in various types of food industries may differ due to their unique features and requirements. The proposed novel framework is conceptual and generic for any FSC. As a result, the framework needs to be verified and advanced through additional empirical studies; feasibility and scalability must also be tested, particularly for specific types of FSCs. Moreover, the conceptual framework illustrates the post-implementation phase of the innovation process, encompassing the routinization and regularization of digital transformation in FSCs. However, this aspect remains unexplored, presenting an additional avenue for future research.

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References

Aamer, Ammar Mohamed, Mohammed Ali Al-Awlaqi, Ifadhila Affia, Silvia Arumsari, and Nabeel Mandahawi. 2021. ‘The Internet of Things in the Food Supply Chain: Adoption Challenges’. *Benchmarking: An international Journal* 28(8):2521–41. (*)

Accorsi, Riccardo, Susan Cholette, Riccardo Manzini, and Alessandro Tufano. 2018. ‘A Hierarchical Data Architecture for Sustainable Food Supply Chain Management and Planning’. *Journal of Cleaner Production* 203:1039–54 (*)

Ali, Mithun Syed, Md Abdul Moktadir, Golam Kabir, Jewel Chakma, Md Jalal Uddin Rumi, and Md Tawhidul Islam. 2019. ‘Framework for Evaluating Risks in Food Supply Chain: Implications in Food Wastage Reduction’. *Journal of Cleaner Production* 228:786–800. (*)

Alloghani, Mohamed, Mohammed M. Alani, Dhiya Al-Jumeily, Thar Baker, Jamila Mustafina, Abir Hussain, and Ahmed J. Aljaaf. 2019. ‘A Systematic Review on the Status and Progress of Homomorphic Encryption Technologies’. *Journal of Information Security and Applications* 48.

Ancarani, Alessandro, Carmela di Mauro, Hervé Legenvre, and Marco Stefano Cardella. 2020. ‘Internet of Things Adoption: A Typology of Projects’. *International Journal of Operations and Production Management* 40(6).

Annosi, Maria Carmela, Federica Brunetta, Francesco Bimbo, and Marianthi Kostoula. 2021. ‘Digitalization within Food Supply Chains to Prevent Food Waste. Drivers, Barriers and Collaboration Practices’. *Industrial Marketing Management* 93:208–20. (*)

Armbrust, Michael, Armando Fox, Rean Griffith, Anthony D. Joseph, Randy Katz, Andy Konwinski, Gunho Lee, David Patterson, Ariel Rabkin, Ion Stoica, and Matei Zaharia. 2010. ‘A View of Cloud Computing’. *Communications of the ACM* 53(4):50–58.

Attaran, Mohsen. 2007. ‘RFID: An Enabler of Supply Chain Operations.’ *Supply Chain Management* 12(4):249–57.

Balsmeier, Benjamin, and Martin Woerter. 2019. ‘Is This Time Different? How Digitalization Influences Job Creation and Destruction’. *Research Policy* 48(8).

Barratt, Mark, and Adegoke Oke. 2007. ‘Antecedents of Supply Chain Visibility in Retail Supply Chains: A Resource-Based Theory Perspective’. *Journal of Operations Management* 25(6):1217–33.

Battistoni, Elisa, Simone Gitto, Gianluca Murgia, and Domenico Campisi. 2023. ‘Adoption Paths of Digital Transformation in Manufacturing SME’. *International Journal of Production Economics* 255:108675.

Beker, Ivan, Milan Delić, Stevan Milisavljević, and Stevan Stankovski. 2016. ‘Can IoT Be Used to Mitigate Food Supply Chain Risk?’ *International Journal of Industrial Engineering and Management* (IJIEM) 7(1):43–48. (*)

Belaud, Jean Pierre, Nancy Prioux, Claire Vialle, and Caroline Sablayrolles. 2019. ‘Big Data for Agri-Food 4.0: Application to Sustainability Management for by-Products Supply Chain’. *Computers in Industry* 111:41–50. (*)

Ben-Daya, Mohamed, Elkafi Hassini, and Zied Bahroun. 2019. ‘Internet of Things and Supply Chain Management: A Literature Review’. *International Journal of Production Research* 57(15–16).

Bogataj, David, Marija Bogataj, and Domen Hudoklin. 2017. ‘Mitigating Risks of Perishable Products in the Cyber-Physical Systems Based on the Extended MRP Model’. *International Journal of Production Economics* 193:51–62. (*)

Bolstorff, Peter, and Robert Rosenbaum. 2003. Supply Chain Excellence: A Handbook for Dramatic Improvement Using the SCOR Model. 2nd ed. New York, AMACOM-American Management Association.

Bourlakis, Michael A., and Paul W. H. Weightman, eds. 2008. *Food Supply Chain Management.* United States: John Wiley & Sons.
Caiado, Rodrigo, Luiz Felipe Scavarda, Luiz Octavio Gaviao, Paulo Ivson, Daniel Luiz de Mattos Nascimento, and Jose Arturo Garza-Reyes. 2021. 'A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management'. *International Journal of Production Economics* 231: 107883.
Cappellesso, Giselle, and Karim Marini Thomé. 2019. 'Technological Innovation in Food Supply Chains: Systematic Literature Review'. *British Food Journal* 121(10):2413–28. (*)
Chaudhuri, Atanu, Iskra Dukovska-Popovska, Nachiappan Subramanian, Hing Kai Chan, and Ruibin Bai. 2018. 'Decision-Making in Cold Chain Logistics Using Data Analytics: A Literature Review'. *International Journal of Logistics Management* 29(3).
Ciccullo, Federica, Margherita Fabbri, Nizar Abdelkafi, and Margherita Pero. 2022. 'Exploring the Potential of Business Models for Sustainability and Big Data for Food Waste Reduction'. *Journal of Cleaner Production* 340:130673. (*)
Creazza, Alessandro, Claudia Colicchia, Salvatore Spiezia, and Fabrizio Dallari. 2022. 'Who Cares? Supply Chain Managers' Perceptions Regarding Cyber Supply Chain Risk Management in the Digital Transformation Era'. *Supply Chain Management* 27(1):30–53.
Coppolino, Luigi, Luigi Romano, Alessandro Scaletti, and Luigi Sgaglione. 2020. 'Fuzzy Set Theory-Based Comparative Evaluation of Cloud Service Offerings: An Agro-Food Supply Chain Case Study'. *Technology Analysis and Strategic Management* 33(8):900–913. (*)
Corallo, Angelo, Martina De Giovanni, Maria Elena Latino, and Marta Menegoli. 2023. 'Leveraging on Technology and Sustainability to Innovate the Supply Chain: A Proposal of Agri-Food Value Chain Model'. *Supply Chain Management*.
Davis, F. D. 1989. 'Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology'. *MIS Quarterly* 13 (3): 319–340.
De, Arkajyoti, and Surya Prakash Singh. 2021. 'Analysis of Fuzzy Applications in the Agri-Supply Chain: A Literature Review'. *Journal of Cleaner Production* 283:124577.
De Haas, Henning, John Bang Mathiasen, and Søren Sjyold. 2021. 'In Search of a Human Dimension of Supply Chain 4.0'. Pp. 261–85 in *Supply Chain 4.0: Improving Supply Chains with Analytics and Industry 4.0 Technologies*, edited by E. Aktas, M. Bourlakis, I. Minis, and V. Zeimpekis. Kogan Page Publishers.
Delen, Dursun, and Hamed M. Zolbanin. 2018. 'The Analytics Paradigm in Business Research'. *Journal of Business Research* 90:186–95.
Denyer, David, David Tranfield, and Joan Ernst Van Aken. 2008. 'Developing Design Propositions through Research Synthesis'. *Organization Studies* 29(3):393–413.
Denyer, David, and David Tranfield. 2009. 'Producing a Systematic Review'. In D. A. Buchanan & A. Bryman (Eds.), The Sage handbook of organizational research methods (pp. 671–689). Sage Publications Ltd.
Do, Quynh Nhu, Nishikant Mishra, Nur Baiti Ingga Wulandhari, Amar Ramudhin, Uthayasankar Sivarajah, and Gavin Milligan. 2021. 'Supply Chain Agility Responding to Unprecedented Changes: Empirical Evidence from the UK Food Supply Chain during COVID-19 Crisis'. *Supply Chain Management* 26(6):737–52.
Donaldson, Dr Andrew. 2022. 'Digital from Farm to Fork: Infrastructures of Quality and Control in Food Supply Chains'. *Journal of Rural Studies* 91:228–35. (*)
Durach, Christian F., Joakim Kembro, and Andreas Wieland. 2017. 'A New Paradigm for Systematic Literature Reviews in Supply Chain Management'. *Journal of Supply Chain Management* 53(4).

EIB Economics Department. 2023. *Digitalisation in Europe 2022–2023 Evidence from the EIB Investment Survey.*

Evans, Dave. 2011. The Internet of Things How the Next Evolution of the Internet Is Changing Everything. Available at: http://www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf (Accessed 30 November 2023).

FAO. 2021. The State of Food Security and Nutrition in the World 2021. FAO, IFAD, UNICEF, WFP and WHO.

FAO. 2022. The Importance of Ukraine and The Russian Federation for Global Agricultural Markets and The Risk Associated with The in Ukraine.

Frederico, Guilherme F., Jose Arturo Garza-Reyes, Anthony Anosike, and Vikas Kumar. 2020. 'Supply Chain 4.0: Concepts, Maturity and Research Agenda'. *Supply Chain Management* 25(2):262–82.

Gantz, John, and David Reinsel. 2011. 'Extracting Value from Chaos'. IDC IView, Sponsored by EMC 1–12.

Ghadge, Abhijeet, Samir Dani, and Roy Kalawsky. 2012. 'Supply Chain Risk Management: Present and Future Scope'. *International Journal of Logistics Management* 23(3).

Ghadge, Abhijeet., Kaklamanou, Merilena, Choudhary, Sonal, and Bourlakis, Michael. 2017. 'Implementing environmental practices within the Greek dairy supply chain: Drivers and barriers for SMEs'. *Industrial Management & Data Systems*, 117(9), 1995-2014.

Ghadge, Abhijeet, Merve Er Kara, Hamid Moradlou, and Mohit Goswami. 2020a. 'The Impact of Industry 4.0 Implementation on Supply Chains'. *Journal of Manufacturing Technology Management* 31(4):669–86.

Ghadge, Abhijeet, Maximilian Weiß, Nigel D. Caldwell, and Richard Wilding. 2020b. 'Managing Cyber Risk in Supply Chains: A Review and Research Agenda'. *Supply Chain Management* 25(2):223–40.

Ghadge, Abhijeet, Wurtmann, Hendrik, & Seuring, Stefan (2020c). Managing climate change risks in global supply chains: a review and research agenda. International Journal of Production Research, 58(1), 44-64.

Ghadge, Abhijeet, Michael Bourlakis, Sachin Kamble, and Stefan Seuring (2023). 'Blockchain implementation in pharmaceutical supply chains: A review and conceptual framework.' *International Journal of Production Research*, 61 (19), 6633-6651.

GOV.UK. 2022. *UK Digital Strategy.* Available at: https://www.gov.uk/government/publications/uks-digital-strategy/uk-digital-strategy#contents (Accessed 30 November 2023).

Hanelt, André, René Bohnsack, David Marz, and Cláudia Antunes Marante. 2021. 'A Systematic Review of the Literature on Digital Transformation: Insights and Implications for Strategy and Organizational Change'. *Journal of Management Studies* 58(5). doi: 10.1111/joms.12639.

Henfridsson, Ola, and Bendik Bygstad. 2013. 'The Generative Mechanisms of Digital Infrastructure Evolution'. *MIS Quarterly* 37 (3): 907-931.

Hinings, Bob, Thomas Gegenhuber, and Royston Greenwood. 2018. 'Digital Innovation and Transformation: An Institutional Perspective'. *Information and Organization* 28(1):52–61.

Irani, Zahir, Amir M. Sharif, Habin Lee, Emel Aktas, Zeynep Topaloğlu, Tamara van't Wout, and Samsul Huda. 2018. 'Managing Food Security through Food Waste and Loss: Small Data to Big Data'. *Computers & Operations Research* 98:367–83. (*)

Irfan, Muhammad, and Mingzheng Wang. 2019. 'Data-Driven Capabilities, Supply Chain Integration and Competitive Performance: Evidence from the Food and Beverages Industry in Pakistan'. *British Food Journal* 121(11):2708–29. (*)

Jagtap, Sandeep, and Linh Nguyen Khanh Duong. 2019. ‘Improving the New Product Development Using Big Data: A Case Study of a Food Company’. *British Food Journal* 121(11):2835–48. (*)

Jagtap, Sandeep, Guillermo Garcia-Garcia, and Shahin Rahimifard. 2021. ‘Optimisation of the Resource Efficiency of Food Manufacturing via the Internet of Things’. *Computers in Industry* 127:103397. (*)

Kamble, Sachin S., Angappa Gunasekaran, and Shradha A. Gawankar. 2020. ‘Achieving Sustainable Performance in a Data-Driven Agriculture Supply Chain: A Review for Research and Applications’. *International Journal of Production Economics* 219:179–94. (*)

Kappelman, Ashton Conrad, and Ashesh Kumar Sinha. 2021. ‘Optimal Control in Dynamic Food Supply Chains Using Big Data’. *Computers & Operations Research* 126:105117. (*)

Kaur, Harpreet. 2019. ‘Modelling Internet of Things Driven Sustainable Food Security System’. *Benchmarking: An international Journal* 28(5):1740–60. (*)

Kayikci, Yasanur, Sercan Demir, Sachin K. Mangla, Nachiappan Subramanian, and Basar Koc. 2022. ‘Data-Driven Optimal Dynamic Pricing Strategy for Reducing Perishable Food Waste at Retailers’. *Journal of Cleaner Production* 344:131068. (*)

Kazancoglu, Yigit, Melisa Ozbiltekin Pala, Muruvvet Deniz Sezer, Sunil Luthra, and Anil Kumar. 2021. ‘Drivers of Implementing Big Data Analytics in Food Supply Chains for Transition to a Circular Economy and Sustainable Operations Management’. *Journal of Enterprise Information Management*. (*)

Koot, Martijn, Martijn R. K. Mes, and Maria E. Iacob. 2021. ‘A Systematic Literature Review of Supply Chain Decision Making Supported by the Internet of Things and Big Data Analytics’. *Computers & Industrial Engineering* 154:107076.

Latino, Maria Elena, Marta Menegoli, Mariangela Lazoi, and Angelo Corallo. 2022. ‘Voluntary Traceability in Food Supply Chain: A Framework Leading Its Implementation in Agriculture 4.0’. *Technological Forecasting and Social Change* 178:121564. (*)

Lerman, Laura V., Guilherme Brittes Benitez, Julian M. Müller, Paulo Renato de Sousa, and Alejandro Germán Frank. 2022. ‘Smart Green Supply Chain Management: A Configurational Approach to Enhance Green Performance through Digital Transformation’. *Supply Chain Management* 27(7):147–76.

Lezoche, Mario, Jorge E. Hernandez, Maria del Mar Eva Alemany Díaz, Herve Panetto, and Janusz Kacprzyk. 2020. ‘Agri-Food 4.0: A Survey of the Supply Chains and Technologies for the Future Agriculture’. *Computers in Industry* 117:103187. (*)

Li, Dong, and Xiaojun Wang. 2017. ‘Dynamic Supply Chain Decisions Based on Networked Sensor Data: An Application in the Chilled Food Retail Chain’. *International Journal of Production Research* 55(17):5127–41. (*)

Li, Zhi, Guo Liu, Layne Liu, Xinjun Lai, and Gangyan Xu. 2017. ‘IoT-Based Tracking and Tracing Platform for Prepackaged Food Supply Chain’. *Industrial Management and Data Systems* 117(9):1906–16. (*)

Luo, Heng, Minjie Zhu, Sengang Ye, Hanping Hou, Yong Chen, and Larissa Bulysheva. 2016. ‘An Intelligent Tracking System Based on Internet of Things for the Cold Chain’. *Internet Research* 26(2):435–45. (*)

Magalhães, Ana Elisa Vianna, Arthur Henrique Gomes Rossi, Izabel Cristina Zattar, Marcos Augusto Mendes Marques, and Robson Seleme. 2019. ‘Food Traceability Technologies and Foodborne Outbreak Occurrences’. *British Food Journal* 121(12):3362–79. (*)

Mangla, Sachin Kumar, Sunil Luthra, Nick Rich, Divesh Kumar, Nripendra P. Rana, and Yogesh K. Dwivedi. 2018. 'Enablers to Implement Sustainable Initiatives in Agri-Food Supply Chains'. *International Journal of Production Economics* 203:379–93.

Merton, R.K. 1968. Social Theory and Social Structure, Reprinted ed. New York: Free Press.

Miranda, Jhonattan, Pedro Ponce, Arturo Molina, and Paul Wright. 2019. 'Sensing, Smart and Sustainable Technologies for Agri-Food 4.0'. *Computers in Industry* 108:21–36. (*)

Mogale, D. G., Abhijeet Ghadge, Krishna Kumar, &. Manoj, Kumar Tiwari, and Manoj Kumar Tiwari. 2020. 'Modelling Supply Chain Network for Procurement of Food Grains in India'. *International Journal of Production Research* 58(21):6493–6512.

Mondragon, Adrian E. Coronado, Christian E. Coronado Mondragon, and Etienne S. Coronado. 2020. 'Managing the Food Supply Chain in the Age of Digitalisation: A Conceptual Approach in the Fisheries Sector'. *Production Planning & Control* 21(3):242–55. (*)

Moysiadis, Theocharis, Konstantina Spanaki, Ayalew Kassahun, Sabine Kläser, Nicolas Becker, George Alexiou, Nikolaos Zotos, and Iliada Karali. 2022. 'AgriFood Supply Chain Traceability: Data Sharing in a Farm-to-Fork Case'. *Benchmarking: An International Journal.* (*)

Nayal, Kirti, Rakesh Raut, Ana Beatriz Lopes de Sousa Jabbour, Balkrishna Eknath Narkhede, and Vidyadhar v. Gedam. 2021. 'Integrated Technologies toward Sustainable Agriculture Supply Chains: Missing Links'. *Journal of Enterprise Information Management.* (*)

O'Connor, Christina, and Stephen Kelly. 2017. 'Facilitating Knowledge Management through Filtered Big Data: SME Competitiveness in an Agri-Food Sector'. *Journal of Knowledge Management* 21(1):156–79. (*)

Page, M.J, McKenzie J.E., Bossuyt P.M., Boutron I., Hoffmann T.C., Mulrow C.D., et al. 2021. 'The PRISMA 2020 statement: an updated guideline for reporting systematic reviews'. *British Management Journal* 2021;372: n71.

Pang, Zhibo, Qiang Chen, Weili Han, and Lirong Zheng. 2015. 'Value-Centric Design of the Internet-of-Things Solution for Food Supply Chain: Value Creation, Sensor Portfolio and Information Fusion'. *Information Systems Frontiers* 17(2):289–319. (*)

Pawson, Ray, and Nick Tilley. 1997. Realistic Evaluation. London: SAGE Publications Ltd.

Pittaway, Luke, Maxine Robertson, Kamal Munir, David Denyer, and Andy Neely. 2005. 'Networking and Innovation: A Systematic Review of the Evidence'. *International Journal of Management Reviews* 5-6: 137-168.

Quetti, Cristina, Federico Pigni, and Alessandro Clerici. 2012. 'Factors Affecting RFId Adoption in a Vertical Supply Chain: The Case of the Silk Industry in Italy'. *Production Planning and Control* 23(4):315–31.

Viet, Quoc Nguyen, Behzad Behdani, and Jacqueline Bloemhof. 2020. 'Data-Driven Process Redesign: Anticipatory Shipping in Agro-Food Supply Chains'. *International Journal of Production Research* 58(5):1302.

Rendon-Benavides, Ruben, Roberto Perez-Franco, Rose Elphick-Darling, Lluís M. Plà-Aragonés, Fernando Gonzalez Aleu, Teresa Verduzco-Garza, and Ana v. Rodriguez-Parral. 2022. 'In-Transit Interventions Using Real-Time Data in Australian Berry Supply Chains'. *TQM Journal*. (*)

Rengarajan, Srinath, Gopalakrishnan Narayanamurthy, Roger Moser, and Vijay Pereira. 2022. 'Data Strategies for Global Value Chains: Hybridization of Small and Big Data in the Aftermath of COVID-19'. *Journal of Business Research* 144:776–87. (*)

Rogers, Everett M. 2003. Diffusion of Innovations. 5th Edition.

Russo, Ivan, Daniel Pellathy, and Ayman Omar. 2021. 'Managing Outsourced Reverse Supply Chain Operations: Middle-Range Theory Development'. *Journal of Supply Chain Management* 57(4):63–85.

Seuring, Stefan, and Martin Müller. 2008. ‘From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management’. *Journal of Cleaner Production* 16(15):1699–1710.

Shams Esfandabadi, Hadi, Mohsen Ghamary Asl, Zahra Shams Esfandabadi, Sneha Gautam, and Meisam Ranjbari. 2022. ‘Drought Assessment in Paddy Rice Fields Using Remote Sensing Technology towards Achieving Food Security and SDG2’. *British Food Journal*. (*)

Shang, Xiaopu, Runtong Zhang, Xiaomin Zhu, and Quan Zhou. 2015. ‘Design Theory, Modelling and the Application for the Internet of Things Service’. *Enterprise Information Systems* 10(3):249–67. (*)

Shukla, Manish, and Sanjay Jharkharia. 2013. ‘Agri-Fresh Produce Supply Chain Management: A State-of-the-Art Literature Review’. *International Journal of Operations and Production Management* 33(2):114–58.

Singh, Akshit, Sushma Kumari, Hanif Malekpoor, and Nishikant Mishra. 2018a. ‘Big Data Cloud Computing Framework for Low Carbon Supplier Selection in the Beef Supply Chain’. *Journal of Cleaner Production* 202:139–49. (*)

Singh, Adarsh Kumar, Nachiappan Subramanian, Kulwant Singh Pawar, Ruibin Bai, and Ruibin Bai RuibinBAI. 2018b. ‘Cold Chain Configuration Design: Location-Allocation Decision-Making Using Coordination, Value Deterioration, and Big Data Approximation’. *Annals of Operations Research* 270:433–57. (*)

Singh, Akshit, Nishikant Mishra, Syed Imran Ali, Nagesh Shukla, and Ravi Shankar. 2015. ‘Cloud Computing Technology: Reducing Carbon Footprint in Beef Supply Chain’. *International Journal of Production Economics* 164:462–71. (*)

Srinivasan, Rengarajan, Vaggelis Giannikas, Mukesh Kumar, Renaud Guyot, and Duncan McFarlane. 2019. ‘Modelling Food Sourcing Decisions under Climate Change: A Data-Driven Approach’. *Computers & Industrial Engineering* 128:911–19. (*)

Stank, Theodore P., Daniel A. Pellathy, Joonhwan In, Diane A. Mollenkopf, and John E. Bell. 2017. ‘New Frontiers in Logistics Research: Theorizing at the Middle Range’. *Journal of Business Logistics* 38(1):6–17.

Stone, Jamie, and Shahin Rahimifard. 2018. ‘Resilience in Agri-Food Supply Chains: A Critical Analysis of the Literature and Synthesis of a Novel Framework’. *Supply Chain Management* 23(3):207–38.

Sundaram, Rammohan, Rajeev Sharma, and Anurag Shakya. 2020. ‘Digital Transformation of Business Models: A Systematic Review of Impact on Revenue and Supply Chain’. *International Journal of Management* 11(5).

Swierczek, Artur. 2023. ‘The Effects of Industry 4.0 Technologies on Relational Performance: The Mediating Role of Supply Chain Emergence in the Transitive Logistics Service Triads’. *Supply Chain Management* 28(2):363–84.

Thibaud, Montbel, Huihui Chi, Wei Zhou, and Selwyn Piramuthu. 2018. ‘Internet of Things (IoT) in High-Risk Environment, Health and Safety (EHS) Industries: A Comprehensive Review’. *Decision Support Systems* 108:79–95. (*)

Tornatzky, L.G. and Fleischer, M. 1990. ‘The Processes of Technological Innovation’. Lexington Books, Lexington.

Tranfield, David, David Denyer, and Palminder Smart. 2003. ‘Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review’. *British Journal of Management* 14(3).

Tsang, Y. P., K. L. Choy, C. H. Wu, G. T. S. Ho, Cathy H. Y. Lam, and P. S. Koo. 2018. ‘An Internet of Things (IoT)-Based Risk Monitoring System for Managing Cold Supply Chain Risks’. *Industrial Management and Data Systems* 118(7):1432–62. (*)

Tsang, Y. P., K. L. Choy, C. H. Wu, G. T. S. Ho, H. Y. Lam, and P. S. Koo. 2017. 'An IoT-Based Cargo Monitoring System for Enhancing Operational Effectiveness under a Cold Chain Environment'. *International Journal of Engineering Business Management* 9:1–13. (*)

Tsang, Y. P., C. H. Wu, H. Y. Lam, K. L. Choy, and G. T. S. Ho. 2020. 'Integrating Internet of Things and Multi-Temperature Delivery Planning for Perishable Food E-Commerce Logistics: A Model and Application'. *International Journal of Production Research* 59(5):1534–56. (*)

van Dun, D.H. and Kumar, M. 2023. 'Social enablers of Industry 4.0 technology adoption: transformational leadership and emotional intelligence'. *International Journal of Operations & Production Management* 43 (13):152-182.

Venkatesh, V., M. G. Morris, G. B. Davis, and F. D. Davis. 2003. 'User Acceptance of Information Technology: Toward a Unified View'. *MIS Quarterly* 425–478.

Verdouw, C. N., R. M. Robbemond, T. Verwaart, J. Wolfert, and A. J. M. Beulens. 2015. 'A Reference Architecture for IoT-Based Logistic Information Systems in Agri-Food Supply Chains'. *Enterprise Information Systems*. (*)

Vial, Gregory. 2019. 'Understanding Digital Transformation: A Review and a Research Agenda'. *Journal of Strategic Information Systems* 28(2):118–44.

Vu, Nam, Abhijeet Ghadge, and Michael Bourlakis. 2023. 'Evidence-Driven Model for Implementing Blockchain in Food Supply Chains'. *International Journal of Logistics Research and Applications*.

Wamba, Samuel Fosso, and Maciel M. Queiroz. 2020. 'Industry 4.0 and the Supply Chain Digitalisation: A Blockchain Diffusion Perspective'. *Production Planning & Control* 33(2–3):193–210.

Wang, Gang, Angappa Gunasekaran, Eric W. T. Ngai, and Thanos Papadopoulos. 2016. 'Big Data Analytics in Logistics and Supply Chain Management: Certain Investigations for Research and Applications'. *International Journal of Production Economics* 176.

Weber, Rolf H. 2009. 'Internet of Things – Need for a New Legal Environment?' *Computer Law & Security Review* 25(6):522–27.

Weersink, Alfons, Evan Fraser, Dave Pannell, Emily Duncan, and Sarah Rotz. 2018. 'Opportunities and Challenges for Big Data in Agricultural and Environmental Analysis'. *Annual Review of Resource Economics* 10:19–37. (*)

Xu, Linqi, Fu Jia, Xiao Lin, and Lujie Chen. 2023. 'The Role of Technology in Supply Chain Decarbonisation: Towards an Integrated Conceptual Framework'. *Supply Chain Management* 28(4):803–24.

Yadav, Sanjeev, Dixit Garg, and Sunil Luthra. 2020a. 'Development of IoT Based Data-Driven Agriculture Supply Chain Performance Measurement Framework'. *Journal of Enterprise Information Management* 34(1):292–327. (*)

Yadav, Sanjeev, Sunil Luthra, and Dixit Garg. 2020b. 'Internet of Things (IoT) Based Coordination System in Agri-Food Supply Chain: Development of an Efficient Framework Using DEMATEL-ISM'. *Operations Management Research* 2020 1–27. (*)

Yadav, Sanjeev, Dixit Garg, and Sunil Luthra. 2022. 'Ranking of Performance Indicators in an Internet of Things (IoT)-Based Traceability System for the Agriculture Supply Chain (ASC)'. *International Journal of Quality and Reliability Management* 39(3):777–803. (*)

Yan, Bo, Chang Yan, Chenxu Ke, and Xingchao Tan. 2016. 'Information Sharing in Supply Chain of Agricultural Products Based on the Internet of Things'. *Industrial Management and Data Systems* 116(7):1397–1416. (*)

Zhang, Yingfeng, Lin Zhao, and Cheng Qian. 2017. 'Modeling of an IoT-Enabled Supply Chain for Perishable Food with Two-Echelon Supply Hubs'. *Industrial Management and Data Systems* 117(9):1890–1905. (*)

NOTE: (*) The articles are from the 57 articles chosen for the SLR review pool.

Appendix

Summary of various implementation architecture with IoT, CC and BDA

	Applied technologies	Number of layers	Specific Architecture
Mondragon et al. (2020)	IoT with BDA	2	• Sensor and network layer • Application layer
Thibaud et al. (2018)	IoT	3	• Identification, sensing, actuation/data exchange/information • Integration/ application • Services
Miranda et al. (2019)	IoT		• Physical component • Smart component and connectivity • Activity of data storage selection and designing the connectivity system
Luo et al. (2016)	IoT		• Sensing layer • Network layer • Application layer
Pang et al. (2015)	IoT		• Device layer • Connectivity layer • IoT cloud layer
Tsang et al. (2018)	IoT with cloud computing		• Device layer • Connectivity layer • IoT cloud layer
Tsang et al. (2018)	IoT	4	• Sensing layer • Gateway/network layer • Management service layer • Application layer
Zhang et al. (2017)	IoT with cloud computing		• Resource layer • Perception layer • Data processing layer • Information sharing service layer
Tsang et al. (2020)	IoT with cloud computing		• Device layer • Network layer • Service layer • Application layer
Tsang et al. (2017)	IoT with cloud computing, BDA		• Device layer • Network layer • IoT cloud layer • Application layer
Jagtap et al. (2021)	IoT with cloud computing		• Sensing layer

			• Network layer • Service layer • Application layer
Li et al. (2017)	IoT	5	• Perception layer • Data layer • Service layer • Application layer • Uses layer