Digital Transformation in Food Supply Chains: A Review and Implementation Roadmap

Shiyi Wang (shiyi.wang.567@cranfield.ac.uk)
Centre for Logistics and Supply Chain Management, Cranfield University, UK

Abhijeet Ghadge (abhijeet.ghadge@cranfield.ac.uk)
Centre for Logistics and Supply Chain Management, Cranfield University, UK

Emel Aktas (emel.aktas@cranfield.ac.uk)
Centre for Logistics and Supply Chain Management, Cranfield University, UK

Abstract

Digital transformation has gradually attracted the attention to address food supply chain (FSC) challenges. However, the integration of technologies/capabilities to achieve digital transformation in FSCs is unclear. The study aims to establish how the digital transformation of FSCs can be achieved using the Internet of Things (IoT), Cloud Computing (CC), and Big Data Analytics (BDA). A systematic literature review (SLR) is conducted to deliver a comprehensive view with 57 papers selected from 2008 to 2022. A digital transformation roadmap is proposed based on the Diffusion of Innovation (DOI) theory, which contributes to theory and practice by providing guidance for implementation.

Keywords: Digital Transformation, Food Supply Chain

Introduction

Food supply chains (FSCs) have recently become the focus of attention due to various global events such as Brexit, the 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). 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 challenges, including food loss and waste (Annosi et al., 2021), poor standards for food safety and quality control (Mangla et al., 2018), traceability issues with real-time transparency (Ben-Daya et al., 2019), a low level of stakeholder collaboration, and the limited involvement of small farmers to achieve sustainable agri-food supply chain (Kamble et al., 2020). Digital transformation has various interpretations. 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/capabilities, including 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., 2020).

A well-developed data management process can form the basis for adopting emerging technologies and developing new capabilities. Different technologies of Industry 4.0 are selected to support the data management process that will enable digital transformation in FSCs. Firstly, IoT systems (e.g., sensors, radio-frequency identification (RFID), cameras, etc.) are used to collect data and provide visibility of supply chain operations with real-time information. Simultaneously, for the vast volumes of data generated by these IoT devices, big data analytics (BDA) is regarded as a powerful tool for analysis, prediction, optimisation, and other decision-making. Cloud computing (CC), being the primary technology supporting connectivity, 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 FSCs. This study focuses on IoT, CC, and BDA as equally important Industry 4.0 technologies/capabilities to enable the digital transformation of FSCs. The development and popularisation of infrastructure and equipment create a favourable environment for the integration of identified technologies (IoT, CC, and BDA) with existing organisational processes. IoT 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). The data transmitted by the IoT can be analysed using BDA tools and techniques to support decision-making (Chaudhuri et al., 2018). IoT and BDA are connected with CC, which 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). Nevertheless, several studies are found to just describe technology applications in FSCs. Most importantly, studies on Industry 4.0 do not address integration opportunities of technologies/capabilities, or they lack in offering approaches to achieve digital transformation. 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.

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 (Rogers, 2003; Hanelt et al., 2021). Thus, this study adopts DOI theory to build a theoretical foundation for implementing digital transformation in FSCs. With appropriate technology/capability support, data from different stages of the FSCs can be efficiently collected, processed, shared, and analysed.

Therefore, 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 answers 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? Attempting to answer this research question, the study provides a implementation roadmap for achieving digital transformation in FSCs.

The rest of the paper is organised as follows: Section 2 demonstrates the methodology used to conduct the SLR. Sections 3 present findings and the implementation roadmap. Finally, the paper concludes with contributions and limitations.

Methodology

An 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). The methodology of this study is based on the three stages of SLR by Tranfield et al. (2003) and the steps from Durach et al. (2017).

The first stage of the SLR is to plan the review. The SLR 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 papers published on IoT and CC started to appear from 2008, which aligns with the emergence of IoT. Scopus, Web of Science (WoS), ABI/INFORM, and Business Source Complete (EBSCO) are selected as the databases for a comprehensive literature search.

The most used keywords are 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’, are not considered. Also, AI and ML are not considered separately since they fall within the field of BDA. Following keyword sorting, corresponding individual and combined search strings are finalised. Then the search strategy is devised based on the research question to guarantee that the results support and derive useful inferences for developing an implementation roadmap.

Later, inclusion and exclusion criteria are defined to include only English publications from 2008 to 2022. In addition, document types are restricted to papers published in academic journals. While practitioner journals, conference proceedings, books, book chapters, and other grey literature (e.g., newspapers, white papers, HTML links, etc.) are excluded. This exclusion of the ‘grey literature’ in SLR studies helps to focus on high-quality publications (Seuring and Müller, 2008; Ghadge et al., 2012).

The second stage is determining the final set of papers and conducting the data synthesis. Firstly, the initial round of searching is carried out by employing inclusion and exclusion criteria. Then, the screening phase seeks to eliminate duplicates and narrow the literature pool using additional criteria by excluding papers in early access publication stage and feature document type. Papers that are irrelevant to the research are excluded during the abstract screening process; for example, publications related to other or associated technologies such as Blockchain, Digital Twins, robots, and other unspecified application areas. Finally, following the screening process described above, 57 papers are selected to form the SLR review pool.

In the last stage of the SLR, emerging themes are identified based on the preliminary survey for conducting the data synthesis and analysis. This reporting and dissemination stage includes reporting the findings of the analysis. The outcome is the implementation roadmap presented in the next section.

Findings and discussion

Emerging technologies of Industry 4.0 play a critical role in enabling digital transformation within the FSCs. Integrated solutions employing IoT, CC, and BDA for FSCs and the storage and sharing stage between data collection and analysis needs more attention. Following the data synthesis and in accordance with the Diffusion of Innovation (DOI) theory, an implementation roadmap of the digital transformation in FSCs is developed (Figure 1). The innovation process of DOI theory provides the theoretical basis for implementing digital transformation since emerging digital technologies are regarded as innovative practices that are able to shift and reshape traditional organisations and industries (Hinings et al., 2018). Specifically, digital transformation emphasises the transition brought by the application of emerging technologies that are different from traditional information technology (Hanelt et al., 2021). The innovation process is divided into two main stages: initiation and implementation, with the adoption decision in between.

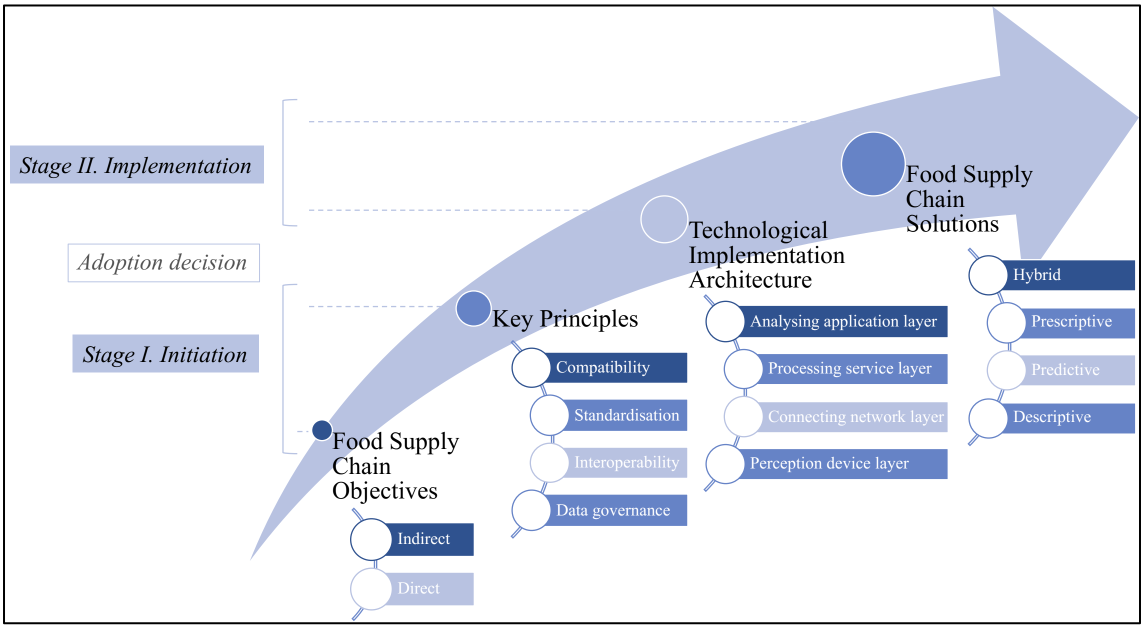

Figure 1 – Implementation roadmap of digital transformation in food supply chains

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 are expected to be achieved by digital transformation in the FSC directly and indirectly. The direct objectives consist of traceability, data and information sharing, and integrating existing and emerging technologies, which will further benefit the indirect objectives. Traceability is one of the most popular research topics in the FSC since an increasing number of studies apply 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). Notably, traceability linked to information sharing using IoT is a significant area of interest, where CC is used as a supporting capability providing the ability to store and share the data collected by the IoT. Indirect objectives include food waste and loss, food safety and integrity, competitiveness, and environmental impacts. They could be reached only with the achievement of direct objectives discussed above.

Subsequently, prior to implementing innovations, critical principles enabling digital transformation in SCs should be set (Beker et al., 2016). The review identify four critical principles, comprising data governance, interoperability, standardisation, and compatibility. Firstly, data governance is broader than data management because 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). 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; 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). Actually, 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). Lastly, compatibility is an important issue in the digital transformation of FSCs, which concerns interactions between sensors, networks, and systems.

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 technological architecture is then applied in the implementation stage to identify suitable Industry 4.0 technologies and their fit in the FSC context. This generic implementation architecture is adapted and conceptualised considering the characteristics and functions of the IoT, CC, and BDA. The architecture comprehensively covers multiple tools and techniques from fundamental technologies/capabilities, which comprises the perception device layer, connecting network layer, processing service layer, and analysing application 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 (Yadav et al., 2020). The detailed choices of tools used in the perception device layer, which comprise different types of IoT (including wireless sensing network (WSN) devices), enable the digital transformation in FSCs. The IoT devices in the perception device layer address challenges like traceability, food safety and quality, particularly in perishable FSCs. Sensors are the core of the perception device layer.

The core mission 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 wireless network. 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. The connecting network layer builds on 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.

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 addressed in the processing service layer and supports information sharing. However, it is rarely mentioned as one of the important capabilities in the literature. To select a suitable cloud service for FSCs, first it is necessary to ensure that the cloud has the required functions, for instance, storing collected data from sensors and providing a supportive platform for optimisation (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 with different objectives and capabilities of stakeholders. In recent years, the "as a service" (_aaS paradigm or XaaS) has received significant 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.

The analysing application layer aims to provide various analyses and decision support in FSCs, where BDA as the underlying technology can be fully exploited. Different algorithms and methods can support BDA to perform a range of analyses based on the support of the previous three layers. In practice, the configuration for the analysing application layer in FSCs is flexible and more oriented to actual problems that need to be solved.

The last step of the implementation roadmap is to form tailored solutions with flexible layers and configuration that allow the processing of abundant data. FSC solutions can be divided into four types, including descriptive, predictive, prescriptive, and hybrid solutions (Delen and Zolbanin, 2018). Reporting and visualisation are largely supported by the IoT and focus on addressing direct objectives like tracking and monitoring. 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; Tsang et al., 2020; Zhang et al., 2017). BDA plays an important role assisting decision-making and strategy provision for different stakeholders in FSCs, for instance, for abattoirs or processors to cut down on emissions (Singh et al., 2018) and retailers to reduce food waste (Kayikci et al., 2022). However, it is rare to see the predictive solution as an independent approach to be used in FSC without integrating with IoT, CC, or BDA.

Conclusion

This study aimed to provide a comprehensive view of the digital transformation in FSCs, enabled by fundamental technologies including IoT, CC, and BDA. Following the SLR, IoT, CC, and BDA integration is emphasised with equal importance to fill the research gaps in addressing integration opportunities of technologies/capabilities and the entire data management process in FSCs. By screening the selected papers, an implementation roadmap based on the DOI theory is proposed following the data synthesis. In the initiation stage of implementing digital transformation, FSCs' direct and indirect objectives, as well as key principles, are identified. Subsequently, the implementation stage follows a four-layer technology architecture, resulting in tailored solutions for various FSC applications. Overall, the added value of the proposed roadmap is its guidance to achieve digital transformation in FSCs through the integration of IoT, CC, and BDA.

The SLR provides a comprehensive view of the digital transformation in FSCs enabled by key technologies of Industry 4.0 and makes contributions to both theory and practice. First, to the best of authors' 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 brings clarity to the intermediate stage of data management between data collection and analysis compared to the previous SLRs in FSCs. The study concludes that IoT, CC, and BDA are equally important Industry 4.0 technologies and capabilities. Moreover, the proposed novel roadmap provides holistic guidelines for the implementation of digital transformation in FSCs based on the DOI theory. 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 for technical capabilities throughout the data management process. The four-layer technical implementation architecture is generalised as an essential component of the implementation roadmap.

Meanwhile, the study contributes to practice by providing insights into the transition from conventional to digital FSCs. This study makes digital transformation concrete through representative technologies, presenting it clearly and making it easier to understand and apply for practitioners. Managers in the food industry can gain insights into stages of implementation along with an understanding of drivers and barriers. The study also raises awareness about technology issues associated with data governance, interoperability, standardisation, and compatibility. In addition, the SLR inspires the food industry to digitalise their SC operations utilising Industry 4.0 emerging technologies. Meanwhile, the findings can assist policymakers in establishing relative standards or rules, which could encourage more stakeholders to accept selected emerging technologies.

There are still some limitations to this study. The review pool included 57 high-quality journal articles published between 2008 and 2022. The authors' bias for interpretation may occur due to the limitations of the number of articles, but this limitation is alleviated by cross-checking from other co-authors. Text mining could be used to validate the choice of keywords. The applications of digital transformation in various types of food industries may differ due to their unique features and requirements. The proposed novel implementation roadmap is conceptual and generic for any FSC. As a result, the roadmap needs to be verified and advanced through additional empirical studies. Feasibility and scalability must also be tested, particularly for specific types of FSCs.

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