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TOPICAL REVIEW

Industry 4.0 Adoption in Food Supply Chain to Improve Visibility and Operational Efficiency–A Content Analysis

VASANTHRAJ[1,2], ARSHINDER KAUR[1], VIDYASAGAR POTDAR[2,3], AND HIMANSHU AGRAWAL[4]
[1]Department of Management Studies, Indian Institute of Technology Madras, Chennai 600035, India
[2]School of Management and Marketing, Curtin University, Perth, WA 6845, Australia
[3]Symbiosis Institute of Technology, Symbiosis International University, Pune 412115, India
[4]School of Electrical Engineering, Computing and Mathematical Sciences, Perth, WA 6845, Australia

Corresponding author: Vasanthraj (vasanthrj46@gmail.com)

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ABSTRACT Food can become unsafe or contaminated at any point from farm to fork. Customers and stakeholders are concerned about food safety and prompt delivery. Hence, there is a need for a visible food supply chain (FSC) which can be accomplished through innovative technologies. However, these technologies are expensive and take a long time to implement. Hence, operational efficiency, which takes into account cost, time, and waste, has become a priority for the parties involved in the FSC. This study aims to conduct a content analysis-based literature review to understand the impact of Industry 4.0 technologies in FSC in terms of visibility and operational efficiency. It is found that Blockchain, Internet of Things, and Radio Frequency Identification are considered to have great potential in the FSC. Although the FSC can tremendously benefit from other technologies, such as artificial intelligence, edge computing, and robots, they are not currently deployed in a practical or efficient way. This study also discovers how supply chain organisations can implement a technology cost-sharing system. Our study includes 16 emerging Industry 4.0 technologies and shows their impact on the FSC, as well as cost-sharing mechanisms. The findings of this work assist firms in technology cost sharing and selecting the right technologies for their supply chain. Finally, a conceptual framework is proposed to show how future work can be done to improve visibility and operational efficiency in the FSC using Industry 4.0 technologies.

INDEX TERMS Content analysis, food supply chain, Industry 4.0, operational efficiency, systematic literature review, visibility.

I. INTRODUCTION

The supply chain phenomenon ensures that the right product reaches the right customer at the right time [1]. It deals with the flow of products, information, and money, where the product can be paper, cloth, food, fuel, etc. The food supply chain (FSC) is more complex than other supply chains because it involves perishable goods, which sometimes need to be stored at cold temperatures to ensure quality. As a result of its perishable nature and long-distance transportation, food contamination has become a severe problem in recent years. For example, in 2015, the US Food Administration refused to import snacks from an Indian company due to high levels of contaminants, such as pesticides and bacteria [2]. In 2017, eggs were contaminated with an insecticide fipronil, in Europe and Asia. During this event, in the UK alone, about 700,000 eggs were contaminated [3]. In 2018, needles were present in strawberries grown in Queensland, Australia [4]. These kinds of incidents frequently recur these days, and therefore, customers are inclined to shop for safe and secure products even if it is more expensive. Also, customers are increasingly interested in traceable and organic food products. This shows the importance of a visible FSC, where the stakeholders can track the products for current location,

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temperature, quality, and more. Such tracking and monitoring help reduce waste and time in the supply chain and certain costs like labour, recall, delay, etc. This reduction in cost, time and waste can be considered operational efficiency, one of the key performance indicators of the supply chain. In a manual supply chain, obtaining this level of visibility and operational efficiency is challenging, necessitating intelligent systems.

Traditional supply chains are primarily manual (not automated) and involve limited use of intelligent systems, which leads to such problems as poor traceability, inefficiency, and data falsification [5], [6], [7]. Customers are increasingly more aware of the quality of the food they consume [8], [9], [10], [11], [12]. Deploying new and evolving data collection technologies are beneficial for all stakeholders and help them make important decisions [13]. For example, the Internet of Things (IoT) and cloud computing (CC) support decision-making in supply chains and improve their performance [14]. Radio Frequency Identification (RFID) can monitor the freshness of perishable products and simultaneously update data on tags [15]. Another technology, blockchain, is a decentralised structure and can be used to track supply chains and avoid fraud [16]. Edge computing (EC) improves the speed of network operations and service delivery, reducing processing time for improved user experience [17]. Therefore, it is evident that there is a need for a change in the traditional FSC by implementing intelligent systems to ensure food quality, make the right decisions, and maintain trust between the supply chain entities. Despite these benefits, only a small portion of food industry firms adopt smart manufacturing [18] due to the initial costs and time associated with these technologies. Hence it is essential to capture the operational efficiency as well, which comprises cost, time, and waste.

From this section, it is evident that there is a need to study and ensure visibility and operational efficiency in the FSC and to understand the role of emerging technologies in the FSC. Since implementing these technologies as an independent entity will not help in exploiting the benefits, it is also crucial to analyse the cost-sharing mechanisms while using technologies. These aspects have not been considered in the existing literature. Hence this study performs a content analysis-based literature review (LR) to understand the impact of Industry 4.0 technologies in the FSC in terms of visibility and operational efficiency. Very few studies provide content analysis based LRs in the field of the FSC. For example, Beske et al. [19] performed an LR combined with content analysis of sustainable FSCs. Their results suggest that dynamic competencies and sustainable practices can improve tracking and tracing, thereby resolving customer demands. Kiss et al. [20] conducted a content analysis of short supply chains and found that the sustainability and circular economy characteristics of short supply chains depend on the type, spatial location, and individual attitudes of the producers and customers. Other similar studies that performed content analysis based LR in the FSCs are presented in Table 1, and their findings are presented in Table 2.

Our study differs from previous studies as it performs a content analysis to show how FSCs can be improved through Industry 4.0 technologies in terms of visibility and operational efficiency. While exploring the challenges and benefits, researchers and practitioners will understand the technology cost-to-benefit ratio throughout the supply chain. Content analysis is chosen for this literature review, as there is not much quantitative research in the field of FSC where Industry 4.0 technologies are used. Also, this method is a systemised and consistent procedure to generate reliable findings [23]. To the best of our knowledge, no content analysis method is provided in the FSC showing how Industry 4.0 technologies can be used to improve visibility and operational efficiency, including cost-sharing mechanisms. This indicates the innovation and significance of this research. The contribution of this study is threefold, as indicated below:

i. In order for the food firms to decide whether or not to use Industry 4.0 technologies in their supply chain, we present the features, benefits, and challenges linked to these technologies.
ii. We list several cost-sharing mechanisms so that decision-making in sharing the technology cost among entities can become more transparent.
iii. In this study, a conceptual framework is also proposed to show how future work can be done to improve visibility and operational efficiency in the FSC using Industry 4.0 technologies.

This paper is structured as follows: Section II gives the theoretical background that explains the importance of visibility and operational efficiency in an FSC and the need for Industry 4.0 technologies. The methodology is presented in Section III. Section IV outlines the findings and are discussed in Section V. The research gaps and future direction are put forward in Section VI along with a proposed framework. It is followed by limitation and conclusion in Section VII and Section VIII, respectively.

II. THEORETICAL BACKGROUND

This section explains the need for Industry 4.0 technologies in the FSC, a list of Industry 4.0 technologies, and the components of visibility and operational efficiency in an FSC.

A. INDUSTRY 4.0 AND RELATED TECHNOLOGIES

Industry 4.0 is the fourth industrial revolution related to automation technology [32]. These technologies are commonly used in the manufacturing industry, but today they also show their presence in other industries, of which the food industry is no exception. The term Industry 4.0 encompasses a variety of technologies; however, a universally recognised and standardised list of these technologies does not currently exist. In this review, we follow the list of Industry 4.0 technologies provided by Núñez-Merino et al. [33] and Oliveira-Dias et al. [34]. It was pointed out that the

TABLE 1. Similar studies.

Area	Study	Visibility	Operational Efficiency	Any Industry 4.0 Technology	Cost-sharing mechanisms
Food waste	Li *et al.* [21]	X	✓	X	X
	de Moraes *et al.* [22]	X	✓	X	X
Traceability	Duan *et al.* [23]	✓	X	Blockchain (BC)	X
	Magalhães *et al.* [24]	✓	X	X	X
Data collection in FSC	Chaudhuri *et al.* [25]	X	X	ICT	X
Sustainability	Kiss *et al.* [20]	X	X	X	X
	Dania *et al.* [26]	X	X	X	X
	Beske *et al.* [19]	X	X	X	X
Food security and safety	Musa and Basir [27]	X	X	X	X
	Thome *et al.* [28]	X	X	X	X
	Ringsberg [29]	X	X	X	X
Transparency	Bayir *et al.* [30]	✓	X	X	X
Integrity in halal FSC	Rejeb *et al.* [31]	✓	X	IoT	X
Visibility & Operational Efficiency	**Proposed study**	✓	✓	✓	✓

technologies which can provide effectiveness and efficiency to industries come under Industry 4.0. They list blockchain, IoT, RFID, artificial intelligence (AI), machine learning (ML), CC, additive manufacturing (AM), augmented reality (AR), virtual reality (VR), robotics, and information communication technology (ICT). In order to explore additional Industry 4.0 technologies, a comprehensive review of relevant literature was conducted to identify those technologies that are associated with Industry 4.0. Table 3 shows the previous studies that provide a list of Industry 4.0 technologies. For example, Zhou et al. [35] listed IoT, cyber physical systems (CPS), ICT, big data (BD), CC and RFID as Industry 4.0 technologies. Other frequently discussed emerging Industry 4.0 technologies, as given in Table 3, including EC, fog computing (FC), CPS, cognitive computing (CgC), and BD. Hence, we focus on these 16 technologies for our review to assess their potential utilisation in the FSC to gain visibility and improve operational efficiency. The description and general applications of these technologies are given in Table 4.

B. VISIBILITY AND OPERATIONAL EFFICIENCY

This subsection covers the concepts of visibility and operational efficiency as well as the prerequisites for a visible FSC with fulfilling operational efficiency.

1) VISIBILITY

The extent to which supply chain partners have on-hand information about the supply chain is called visibility [58]. It is the ability to see what is happening in the supply chain and indicates the extent to which supply chain entities have access to key information that they deem helpful to their operations [59], [60]. Managers can reduce supply and demand uncertainty by increasing supply chain visibility [61]. Furthermore, the lack of visibility increases the risk of product recalls [62].

It is imperative to understand the characteristics and subsets of visibility. The visibility of the supply chain can be generally defined as the transparency and traceability of supply chain processes [63]. Zhang and Su [64] mentioned that traceability signifies the visibility of the dissemination process and information provenance. They also state that from the standpoint of the whole supply chain, the terms ‘‘supply chain transparency’’ and ‘‘supply chain visibility’’ can be interchangeable to check how much the consumer gets the appropriate information from the upstream entities of the supply chain. If there is a decline in the agility of traceability, visibility shall move away from the high level to the medium level or low, or from being transparent to translucent [65], [66]. Thus, both transparency and traceability may be seen as key elements of visibility. While ***traceability*** is

TABLE 2. Similar studies and their findings.

Area	Study	Findings
Food waste	Li *et al.* [21]	They found confounding factors like inconsistency in calculation methods for measuring food loss and waste, inconsistency in definitions, and some research gaps.
	De Moraes *et al.* [22]	This study found some causes of food waste and reduction practices in the retailing sector. Operational procedures, materials, and machines are the major problems of food waste.
Traceability	Duan *et al.* [23]	Blockchain can improve traceability, transparency, and efficiency. This study also proposes a lack of understanding, data manipulation, technology difficulties, etc., as some of the main challenges of using blockchain.
	Magalhães *et al.* [24]	Evolution of technologies is one of the major factors in reducing the number of food outbreaks in countries like the USA and Germany.
Data collection in FSC	Chaudhuri *et al.* [25]	Cold chain firms should implement appropriate technologies to capture and store data in the cold chain. Product deterioration can be controlled by analysis of these data.
Sustainability	Kiss *et al.* [20]	The sustainability features and circular economy of short supply chains depend on their type, spatial location, and individual attitudes of the producers and customers.
	Dania *et al.* [26]	Joint efforts, collaboration value, trust, sharing activities, adaptation, power, commitment, coordination, continuous improvement and stability are the ten behavioral factors for a sustainable FSC with a successful collaboration system.
	Beske *et al.* [19]	Dynamic capabilities and sustainability practices can be used to improve tracking and traceability, thus fulfilling customer demands.
Food security and safety	Musa and Basir [27]	Found the impacts of Covid-19 in the FSC. The main impacts are disruption, trade interruption, food consumption, and declining trust of consumers.
	Thomé *et al.* [28]	Proposed a conceptual framework to describe the co-existence between FSC and short FSCs, and found that supply chains are dynamic and change in shape, size, and configuration.
	Ringsberg [29]	They found eight perspectives on the traceability of food - complexity, identification of goods, interoperability, transparency, outsourcing, food quality requirements, production, and monitoring.
Transparency	Bayir *et al.*[30]	Found the challenges in short FSCs at the strategic, tactical, and operationallevelsl.
Integrity in Halal FSC	Rejeb *et al.* [31]	IoT improves traceability, efficiency, facilitation, authentication, and monitoring in halal FSCs.

the ability to track the flow of products in the supply chain [67], ***transparency*** is the degree to which each entity can understand and access the information it requires without any delay, interference, loss or distortion [68].

Visibility is considered the superset of traceability due to its primary importance on transparency and secondary importance on provenance [69]. It is the technology-enabled provenance and transparency [63]. Provenance forms a

TABLE 3. Industry 4.0 technologies.

Studies	Purpose	Technologies under Industry 4.0
Zhou *et al*. [35]	Summarised major trends of future manufacturing and introduced some enabling technologies about Industry 4.0.	IoT, RFID, CC, BD, CPS, ICT
Oesterreich and Teuteberg [36]	To study the state of practice and the state of the art of Industry 4.0 related technologies in the construction industry	IoT, RFID, CC, CPS, VR, AR, AM, robotics, mobile computing
Hofmann and Rüsch [37]	To explore the opportunities of Industry 4.0 in logistics management.	IoT, RFID, CC, BD, CPS, AR, 3D printing, robotics, blockchain, internet of services,
Liao *et al*. [38]	Proposed a systematic literature review to analyse the academic progress in Industry 4.0.	IoT, RFID, CPS, VR, AR, 3D printing, industrial robots (robotics), ML, industry internet, internet protocol
Bibby and Dehe [39]	An assessment model is proposed to analyse the level of implementation of Industry 4.0 technologies in three dimensions: Factory of the Future, People and Culture, and Strategy.	IoT, CC, CPS, VR, AR, AM, robotics, blockchain, sensors, manufacturing execution system
Xu *et al*. [32]	To introduce the industrial sectors communities to the existing developments and future scopes in the field of Industry 4.0.	IoT, RFID, CC, CPS, ICT, robotics, blockchain, AI, ML, CgC
Mariani *et al*. [40]	To provide a clear vision of the existing structure of Industry 4.0 in management studies through a bibliometric analysis.	Autonomous robots, IIoTs, cyber security, cloud, AM, AR.
Queiroz *et al*. [41]	A literature review is proposed to focus on recent studies on Industry 4.0 and to develop a SIMPLE framework.	IoT, RFID, CC, BD, CPS, VR, AR, autonomous robots, blockchain, AI, physical internet, digital twin, sensors
Demestichas [42]	To conduct a literature review on leading ICT solutions covering the way towards the circular economy.	IoT, RFID, CC, BD, CPS, ICT, VR, AR, AM, blockchain, AI, ML, EC, digital twin, GIS
Sittón-Candanedo [43]	To review the existing Edge Computing reference architectures focussed on Industry 4.0 and compare these reference architectures to build a new Edge Computing Architecture.	IoT, CC, blockchain, EC
Shah *et al*. [44]	To understand the cyber-attacks related to IoT devices and mention how to mitigate those attacks.	IoT, CC, CPS, FC, CgC
Caiza *et al*. [45]	To propose a systematic review of the architecture, latency, security, and energy	IoT, RFID, CPS, robotics, FC, IIoT
	consumption that fog computing presents at the industrial level.	

TABLE 4. Description and applications of the selected technologies.

Sl No.	Technologies	Description	Applications
1	Blockchain	An immutable shared distributed ledger composed of blocks that contains transaction data which are traceable [6]	Banking, finance, insurance
2	IoT	A network of wireless devices connected with each other to transfer data through an internet connection [31].	Industrial automation, environmental monitoring, transportation and logistics
3	RFID	A device used to automatically identify objects with the help of radio waves within a specified radio frequency range [46].	Asset tracking, animal tracking, waste management
4	Artificial intelligence	The information that is exhibited by a machine or screen in comparison to the original information exhibited by humans or animals [47].	Autonomous vehicles, smart assistance
5	Machine learning	The algorithms, which develop computer programs to access data and use these data to learn themselves [48].	Precision farming, demand prediction, livestock monitoring
6	Cloud computing	A data storage platform that provides management, maintenance, and backup of data [49].	Data storage, precision farming
7	Additive manufacturing	The process of creating objects by joining materials layer by layer with reference to a 3D model [50].	Urban farming, prototyping, customised food items
8	Augmented reality	A technology that enhances the real-life environment by including digital and virtual elements like graphics, images, etc. [51].	Tourism, gaming, crop scouting
9	Virtual reality	A technology that can be used to interact with a virtual environment and provide information [52].	Gaming, e-learning, farm planning
10	Robotics	Branch of AI that deals with the design, operation and construction of robots [53].	Defense, space exploration, greenhouse automation
11	ICT	A broad range of technological resources and techniques that are used to	Communication, telemedicine, farm automation

TABLE 4. ***(Continued.)*** **Description and applications of the selected technologies.**

		create, transfer, store, share, and exchange information.	
12	Cognitive computing	A technology that matches the human capacity in making logical decisions [54].	Decision support systems, e-learning, farm automation
13	Edge computing	It is a platform that makes the computation to happen at the proximity of source of data to reduce the response time and energy consumption [55].	Data storage, autonomous vehicles, precision agriculture
14	Fog computing	It is a virtualised platform that computes, stores and provides networking services between end devices and cloud computing [56].	Smart power grids, autonomous vehicles, smart irrigation
15	Big data	The data which are of high volume and wide variety, created with a high speed [48].	Business analytics, customer relationship management, weather forecasting
16	Cyber physical systems	These are the physical systems that act as sensors to collect real data and transfer to a cyber layer that analyses the data and transfers the finding back to the physical devices [57].	Diagnostics, prognostics, monitoring

critical notion to adopt the agenda of information declarations within the supply chain visibility towards accessibility of product–process origin among the supply chain entities [70]. Also, active provenance needs to be facilitated to cater to the agenda of visibility. Somapa et al. [71] present a systematic review to determine the characteristics and effectiveness of supply chain visibility. They found that the essential transformational characteristics include monitoring daily and hourly sales of products and the schedule of deliveries. The visibility of a supply chain system can be increased by automating monitoring systems, and the suggested benefit of monitoring processes is increased process visibility [72].

Furthermore, ubiquitous temperature monitoring is essential for improving process visibility in such applications as cold supply chain management [73]. Hence provenance and monitoring can also be considered as other prerequisites of visibility. While the process or method used to track the origin of a product is called ***provenance*** [56], ***monitoring*** is defined as a process that ensures entities are sticking to specific commitments and taking corrective actions if required [74].

From these studies, it is clear that visibility is an essential requirement in an FSC, and traceability, transparency, monitoring and provenance are some of the critical components or subsets or replacements of visibility. Table 5 supports this argument by showing the previous studies that mention the components of visibility. While traceability, provenance and monitoring are related to food products, transparency is related to data and information. Hence, in order to study visibility, this review considers papers that also talk about traceability, transparency, monitoring, and provenance.

2) OPERATIONAL EFFICIENCY

Operational efficiency can be defined as the ability of an organisation to reduce the wastage of inputs and maximise the utilisation of resources [75]. The resources refer to cost and time. Several studies have reported one or more of these dimensions. It is one of the significant challenges faced by firms and can be improved by waste minimisation strategies [76].

A few studies state how operational efficiency can be improved. Zhou and Piramuthu [77] asserted that this could be achieved by improving product quality and reducing waste. Using RFID technology to gather shelf-life information, Wang and Li [78] increased profits and decreased waste, which helped in improving the operational efficiency of the FSC. Sert et al. [79] investigated the relationship between

TABLE 5. Studies showing components of visibility.

Sl No.	Studies	Purpose	Visibility component
1	Tse and Tan [63]	A quality risk management framework, with the help of a case study, is proposed for a supply chain product by integrating calculus and marginal analysis.	Transparency, traceability
2	Zhang *et al.* [64]	Inspect a coordination mechanism in an FSC where the cost and demand are sensitive to the visibility of the supply chain.	Traceability, provenance
3	Francisco *et al.* [65]	To explore the applications of blockchain in supply chain traceability using the Unified Theory of Acceptance and Use of Technology.	Traceability
4	Kraft *et al.* [66]	To study how a profit driven supplier is motivated by a profit driven firm to practice better social responsibility which are not perfectly observed by the firm.	Traceability
5	Roy [69]	To establish a contrast between supply chain traceability and supply chain visibility	Traceability, provenance
6	Montecchi *et al.* [70]	To develop a provenance-based framework to reduce perceived risks and enhance assurances through blockchain applications	Provenance
7	Somapa *et al.* [71]	To present a literature review to show the characteristics of supply chain visibility and to identify the metrics of supply chain visibility in business processes.	Monitoring
8	Anitha *et al.* [72]	To show the role of internet of things in improving supply chain visibility and their impact on supply chain performance.	Monitoring
9	Bhattacharyya *et al.* [73]	To develop a low-cost temperature sensor using the ultra-high frequency RFID as a sensor device for improving the visibility	Monitoring

cost reduction concerns and humanitarian decision-making to understand the impact of operational efficiency as a key reason for corporate in-kind donations. They stated that cost and cost savings are aspects that must be considered in order to achieve operational efficiency. Manikas and Sundarakani [80] studied the operational efficiency of a slaughterhouse by considering all aspects of waste disposal, government regulations, and resource utilisation (time taken by employees) by creating a relationship between them. They argued that performance is on par with the product of waste management, government regulations and time. Li and O'Brien [81] focused on improving the efficiency of the supply chain by improving the lead time, profitability, waste elimination, and speedy delivery. Vlachos [46] stated that reduced lead times and inventory could increase operational efficiency. As a result, it can be said that the operational efficiency of a supply chain mainly depends on cost, time, and waste. Table 6 supports this argument by showing the previous studies that mention the components of operational efficiency. Therefore, for operational efficiency in this study, we will also review the existing literature on cost, time, and waste in the FSC.

C. COST SHARING MECHANISM

The supply chain incurs various expenses. Every constituent entity within a supply chain bears a certain cost responsibility. The unequal distribution of costs among entities creates an inherent unfairness, necessitating the implementation of a cost sharing mechanism to address this issue. According to Xu et al. [82], implementing a cost-sharing mechanism can mitigate the impact of double marginalisation compared to a non-profit sharing mode, which can potentially lead to channel conflicts. Studies conducted by Sun et al. [17], Kim and Hwang [83], and Xie et al. [84] have found that the implementation of a cost sharing mechanism enhances the overall profits of the supply chain entities. Cost sharing has the potential to motivate various entities within a supply chain to enhance product quality and increase overall

TABLE 6. Studies showing components of operational efficiency.

Sl No.	Studies	Purpose	Operational Efficiency components
1	Zhou and Piramuthu [77]	To propose a framework to assist remanufacturing and recycling based on the visibility ability enabled by RFID	Waste
2	Wang and Li [78]	To reduce food wastage and increase the profit of a food retailer by developing a pricing system based on a dynamically identified shelf life with the help of monitoring devices.	Cost, Waste
3	Sert *et al.* [79]	To find out whether and when the operational efficiency in a supply chain plays a role in the case of surplus food donations by food corporate.	Cost
4	Manikas and Sundarakani [80]	To analyse the factors that affect the operational efficiency in a meat supply chain with the help of a simulation model in a slaughter.	Waste, time
5	Li and O'Brien [81]	To analyse the supply chain performance at the chain level and operations level by improving the profit, lead time, delivery promptness, and waste elimination.	Waste, time, cost
6	Vlachos [46]	To determine how RFID adoption can improve the performance of an agri-food supply chain by taking food cooperatives as a case study.	Time

profits [85]. According to Hu et al. [86], implementing a cost-sharing mechanism can potentially enhance a supplier's capacity investment levels, thereby alleviating the financial strain associated with a capacity investment. In addition, this mechanism has the potential to enhance the reliability of supply chain entities by mitigating disruptions, all while maintaining the current total cost of the supply chain [87], [88]. According to Boukherroub et al. [88], implementation of a cost sharing mechanism can result in an increase in the production capacity of supply chain entities. Therefore, discussing how the supply chain entities should share the cost among themselves when using technologies is imperative. Hence, this review also explores several cost sharing mechanisms that companies can utilise to implement Industry 4.0 technologies in an FSC.

This theoretical background has provided a list of Industry 4.0 technologies and their role in enhancing the visibility and operational efficiency of an FSC. It also addressed the significance of cost-sharing mechanisms. In the proceeding sections, we will investigate the features, benefits, challenges, and cost-sharing mechanisms, while using these technologies.

III. METHODOLOGY

This study adopts a content analysis-based literature review to investigate the use of Industry 4.0 technologies for visibility and operational efficiency in the FSC. Content analysis is a type of literature review where researchers analyse text. A text can be any word, theme, paragraph, article, conference article, journal or any other grey article that deals with a particular topic of interest. It can be quantitative and qualitative, quantifying studies through descriptive statistics and critical analysis. Based on the content analysis presented by Harris [89] and Duan et al. [23], we apply the following steps for our literature review.

(i) Form research questions
(ii) Decide on the unit of analysis
(iii) Inclusion and exclusion criteria
(iv) Searching database

(v) Coding and data analysis
(vi) Report findings

A. RESEARCH QUESTIONS

The first step in content analysis is formulating the research questions. As was evident from Introduction Section, using technologies will significantly reduce food-related incidents as it increases visibility. At the same time, there is an argument in the literature that these technologies come at a high cost. So, it is also essential to capture operational efficiency, which deals with reducing and optimising costs, time, and waste. Furthermore, deploying these technologies as a stand-alone entity will not help to reap the benefits. The lack of appropriate cost-sharing mechanisms or incentives has significantly hampered the application of technologies throughout the supply chain. A practical and realistic system can be developed and deployed through an appropriate cost-sharing mechanism to motivate all the FSC actors to implement technologies in the supply chain. However, there is a dearth of work utilising Industry 4.0 technologies to improve visibility, operational efficiency, cost-benefit analysis and technology cost-sharing in the FSC. Therefore, this article aims to answer the research questions in Table 7 with justifications and data extraction.

B. UNIT OF ANALYSIS

The unit of analysis considered here is journal publications mentioning that Industry 4.0 technologies can be used to improve the FSC in terms of visibility, traceability, transparency, monitoring, and provenance. It also includes journal publications that used Industry 4.0 technology in the FSC to improve operational efficiency by reducing cost, time, and waste.

C. INCLUSION AND EXCLUSION CRITERIA

In the inclusion and exclusion criteria, specific guidelines are set to filter the works to be chosen for the review. Table 8 lists these criteria for our study.

D. SEARCHING DATABASE

Scopus, Web of Science, and Science Direct are the databases used, as these contain a large amount of management related work and are mainly used for academic research. This study exclusively examines publications released between 2011 and 2021, as this timeframe coincides with the advancement of Industry 4.0 technologies. Also, prior to 2011, the academic literature did not encompass the concept of Industry 4.0. Table 9 presents the search strings utilised for visibility and operational efficiency, which were used separately. A search was conducted using the title, abstract, and keywords. The disparity in the count of keywords between Science Direct and the other two databases is attributed to the former's restriction of 8 boolean variables, (like OR, AND, etc.). Here a few papers, like Prashar et al. [90], capture both visibility and operational efficiency.

E. CODING AND DATA ANALYSIS

On applying the search strings in the search databases, we received 311 articles in the first phase. In the second phase, we read the abstracts after removing duplicates and selected only 112 articles for further analysis. Other papers are eliminated because they are either using technologies we are not considering (for example, nanotechnology, biotechnology, etc.), or they are more related to the information systems domain than the supply chain. For example, Lu and Bowles [91] looked at nanotechnology applications in the FSC. Because this study did not use any of the technologies listed in Section II, it was not considered in our content analysis.

After reading 112 articles in the third phase, 20 articles were eliminated because they were not relevant to the proposed work. For example, Renko et al. [92] discussed how retailers ensure food quality and safety. They do not use any specific technology and are not related to visibility or operational efficiency. So, finally, 92 papers were selected in the fourth phase, and a content analysis was performed on these studies. Figure 1 explains the steps involved in selecting the articles. The 92 studies are given in Table 10.

As shown in Table 10, out of the 92 studies reviewed, 53% of articles discuss blockchain, 30% discuss RFID, and 32% discuss IoT. Other technologies used or mentioned are EC, ML, BD, CPS, CC, FC, and ICT. It can be seen that the existing research on the FSC has given little importance to such technologies as AI, AR, AM, VR, robotics, and CgC. We will discuss this further by answering our research questions.

IV. FINDINGS

Through our systematic literature review (SLR), we could answer the research questions stated in section III in the following subsections.

A. WHAT ARE THE FEATURES OF INDUSTRY 4.0 TECHNOLOGIES THAT CAN BE USED IN AN FSC?

As previously mentioned, visibility can be improved through traceability, provenance, monitoring, and transparency, and operational efficiency through reduced cost, time, and waste. The 92 papers shown in Table 10 are reviewed. Among these studies, the studies that mention the themes related to a visible supply chain are (traceability, provenance, monitoring, and transparency) presented in Table 11. Here traceability refers to tracking the FSC, especially in the case of a food recall, food inborne illness, etc.; provenance is finding out the details of the farmer like location, farm details, etc.; monitoring is to monitor the FSC so that the stakeholders can reduce the inventory of perishable food products, and transparency is getting as much as information about the food product, such as time of harvest, temperature maintained, processes involved, and so on. We also found the studies that mention the themes related to operational efficiency (cost, time, waste) in an FSC, which are given in Table 12. We observed that

TABLE 7. Research questions and justification.

Research Questions	Justification / Discussion	Data Extraction
RQ-1 What are the features of Industry 4.0 technologies that can be used in an FSC?	To give a basic idea on knowledge of the features of Industry 4.0 technologies and to know the importance of implementing these technologies in the FSC.	To answer this question, we extract which parameters of visibility (traceability/transparency/ provenance/monitoring) or operational efficiency (cost/time/waste reduction) are mentioned in the existing studies.
RQ-2 How do the features of Industry 4.0 technologies impact the performance of the FSC in terms of visibility and operational efficiency?	To develop the knowledge of supply chain entities to consider the possibility of implementing Industry 4.0 technologies in their supply chains, and also to know whether visibility and operational efficiency in an FSC can be improved by using the Industry 4.0 technologies.	To answer this question, we investigated the advantages of Industry 4.0 technologies that contribute to increased visibility and operational efficiency in the supply chain.
RQ-3. What are the challenges of using Industry 4.0 technologies in the FSC?	To understand the challenges that will be faced while using Industry 4.0 technologies, so as to find a trade-off or to make a cost-benefit analysis.	To answer this question, we went on to find several challenges and cite which of the challenges are mentioned in the existing research regarding visibility and operational efficiency.
RQ-4. How can technology costs be shared among various entities of the FSC?	To motivate the supply chain entities to use technologies in their supply chain and improve coordination among them.	To answer this question, we find out which technology is covered in the study and how its cost is shared among the supply chain entities.

very few studies showed how operational efficiency can be improved in the FSC through Industry 4.0 technologies.

We further identified from the review that the features of Industry 4.0 technologies improve traceability, provenance, monitoring, and transparency and also reduce costs, time, and waste in an FSC. These features are digitalisation of data [104], [136], disintermediation [93], [161], data storage [100], [101], data security [94], [154], accountability [99], [105], reliability [93], [94], immutability [95], [161], tamper-proof data [55], [108], integrity [11], [109], automation [101], [148], compliance [109], [18] and data efficiency [11], [167]. The features of each technology are shown in Table 13. Only these features are selected because of their high frequency in the existing literature. The features of each technology are explained below.

Blockchain can store all the data related to the supply chain from farm to fork. It is a peer-to-peer network that engages stakeholders and eliminates the need for intermediaries, thereby ensuring fair payments to the farmers. Data entered into a blockchain cannot be altered. Only authorised entities who have received permission can access the data inside the blockchain, which ensures the integrity of the data. Hence, no stakeholder can modify any data in the event of food incidents. These attributes of blockchain help maintain disintermediation, secured data, reliability, immutable data, tamper-proof data, and integrity. Blockchain also helps in reduced delay [109], [114], [119], [153], thus maintaining the freshness of products and reducing the costs due to delays in product delivery.

RFID has the ability to uniquely identify objects and capture information in real time. These tags transmit information about the real-time location, temperature, and humidity during the shipment of food products and can even transfer the information to the blockchain, thus automating information storage. RFID scanners in food products indicate whether a product is leaving from its rightful owner, thus preventing breaches and thefts. Hence, it can be used for transparency, secured data, efficiency, reliability, integrity, and delay reduction. It can also reduce total cost, time, and waste in an FSC, as given in Table 12. For example, Wang and Li [78] used RFID in a meat supply chain to reduce cost and wastage, whereas Pang et al. [132] and Vlachos [46] used RFID to minimise cost and time in the fruit supply chain.

Likewise, IoT devices use sensors to monitor the location, temperature, humidity, movement, handling, travel speed, and other environmental factors to trace food products. They

TABLE 8. Inclusion and exclusion criteria.

Criteria No.	Criteria Topic	Inclusion Criteria	Exclusion Criteria	Related research question
1	Type	Journal	Grey articles	All
2	Language	English	Papers in languages other than English are excluded.	All
3	Year range	2011 – 2021	Papers published before 2011 were excluded as there were not much progress in industry 4.0 technologies before 2011.	All
4	Technology	Studies that use at least one emerging Industry 4.0 technology listed in section II.	Studies that use technologies like biotechnology, nanotechnology, WSN, GPS and other non-industry 4.0 technologies are excluded.	All
5	Regarding Visibility	Studies that focus on traceability or transparency or monitoring or provenance in FSC.	Papers that focus more on supply chain finance, assets, transportation, etc., which are not specific to visibility.	RQ 1, 2 & 3
6	Regarding Operational efficiency	Studies that work on the reduction in cost, time or waste in an FSC	--	RQ 1, 2 & 3
7	Regarding Challenges of using industry 4.0 technologies	All studies in 5 & 6 that mention the challenges of using any Industry 4.0 technology listed in section II.	--	RQ 3
8	Regarding cost-sharing mechanisms	All studies in 5 & 6 that mention any cost-sharing mechanism while using any Industry 4.0 technology	--	RQ 4

can also monitor packaging conditions, helping to enhance quality management. Goods can remain tagged with IoT devices in a distribution center. This can make it much easier to find specific products within a large warehouse and ensure accurate product identification and management. It can reduce delivery time [168] and hence maintain the freshness of the product. In addition, they help prevent theft [29], prevent shrinkage and errors in inventory [124], improve interest rates [123], resource utilisation, and demand forecasting [168].

In addition to blockchain, RFID, and IoT, other technologies, such as EC, ICT, CC, FC, BD, ML, and CPS can also be used in the FSC. Due to the vast number of stakeholders in the FSC, a lot of data is present, which increases network latency. EC can be employed in these circumstances because it increases efficiency by reducing latency [18]. It collects data [164], reduces data processing costs, and improves response times by performing computations on the edges instead of the cloud [169]. FC can also increase traceability and monitoring by storing, providing, and computing data close to the end user [163]. The combination of CPS and FC can also trace the FSC with increased speed and latency.

FC and CC help with automation, reduced retrieval time, data security, data storage, and algorithm integration [165].

TABLE 9. Search strings used for visibility and operational efficiency.

Database	Keywords for Visibility	Keywords for Operational Efficiency	Number of studies
Scopus & Web of Science	(("agriculture supply chain" OR "agri supply chain" OR "food supply chain") AND ("technology" OR "rfid" OR "industry 4.0" OR "iot" OR "blockchain" OR "edge computing" OR "artificial intelligence" OR "machine learning" OR "big data" OR "autonomous" OR "cyber physical system" OR "cyber security" OR "cloud" OR "additive manufacturing" OR "augmented reality" OR "virtual reality" OR "robotics" OR "3D printing" OR "fog computing" OR "cognitive computing" OR "smart supply chain" OR "logistics 4.0" OR "supply chain 4.0" OR "information and communication technology") AND ("traceability" OR "transparency" OR "visibility" OR "monitoring" OR "provenance"))	(("agriculture supply chain" OR "agri supply chain" OR "food supply chain") AND ("technology" OR "rfid" OR "industry 4.0" OR "iot" OR "blockchain" OR "edge computing" OR "artificial intelligence" OR "machine learning" OR "big data" OR "autonomous" OR "cyber physical system" OR "cyber security" OR "cloud" OR "additive manufacturing" OR "augmented reality" OR "virtual reality" OR "robotics" OR "3D printing" OR "fog computing" OR "cognitive computing" OR "smart supply chain" OR "logistics 4.0" OR "supply chain 4.0" OR "information and communication technology") AND ("operations efficiency" OR "operational efficiency" OR "operation efficiency") AND ("reduction" OR "optimisation" OR "optimisation") AND ("price" OR "time" OR "cost" OR “waste” OR “wastage”)	Scopus – 179 Web of Science - 113
Science Direct	("agriculture supply chain" OR "agri supply chain" OR "food supply chain") AND technology AND (visibility)	("agriculture supply chain" OR "agri supply chain" OR "food supply chain") AND technology AND (operational efficiency)	19

CC helps track and plan shipments and transportation and also helps with traceability and reducing operating costs. ML can improve efficiency by modeling data [166] and thus helps forecast the demand for a food product. They can be integrated with RFID to determine the orientation of the tags. ML can also provide early warnings of disturbances [170], which helps reduce food recalls. These features of Industry 4.0 technologies show the significance of these technologies in an FSC. Hence, it is imperative to understand how these features help in improving visibility and operational efficiency so that industries can have practical usage of these technologies in their supply chain.

B. HOW DO THE FEATURES OF INDUSTRY 4.0 TECHNOLOGIES IMPACT THE PERFORMANCE OF THE FSC IN TERMS OF VISIBILITY AND OPERATIONAL EFFICIENCY?

In the previous section, the features of Industry 4.0 technologies that can be used in an FSC are identified. Figure 2 shows how these features lead to improved visibility and operational efficiency. For instance, data that is accountable, integral, immutable, secured, reliable, compliant, automated, or digital can improve traceability. Likewise, digital and automated data can improve monitoring. Table 14 presents the studies that mention which of these features can improve the components of visibility and operational efficiency. Based on the number of papers, this table can also help us to determine the most appropriate feature for any given aspect of visibility and operational efficiency. For example, digitalisation is the most appropriate feature for traceability, while disintermediation has been found to be the most effective approach for reducing costs. These features are detailed below.

Disintermediation - Disintermediation means removing an intermediary in a supply chain [171]. The current FSCs involve a large number of middlemen. Technologies in FSC help in disintermediation which improves provenance and transparency. This also reduces costs and lead time. In our review, as given in Table 14, one study indicated that non-intermediary could improve provenance [161], two studies indicated that it increases transparency [94], [111] and two studies showed that it reduces time [8], [90] and eight studies indicated that it reduces overall costs [8], [90], [96], [97], [99], [110], [144], [161]. For example, Tsolakis et al. [94] mentioned that eliminating the need for intermediaries

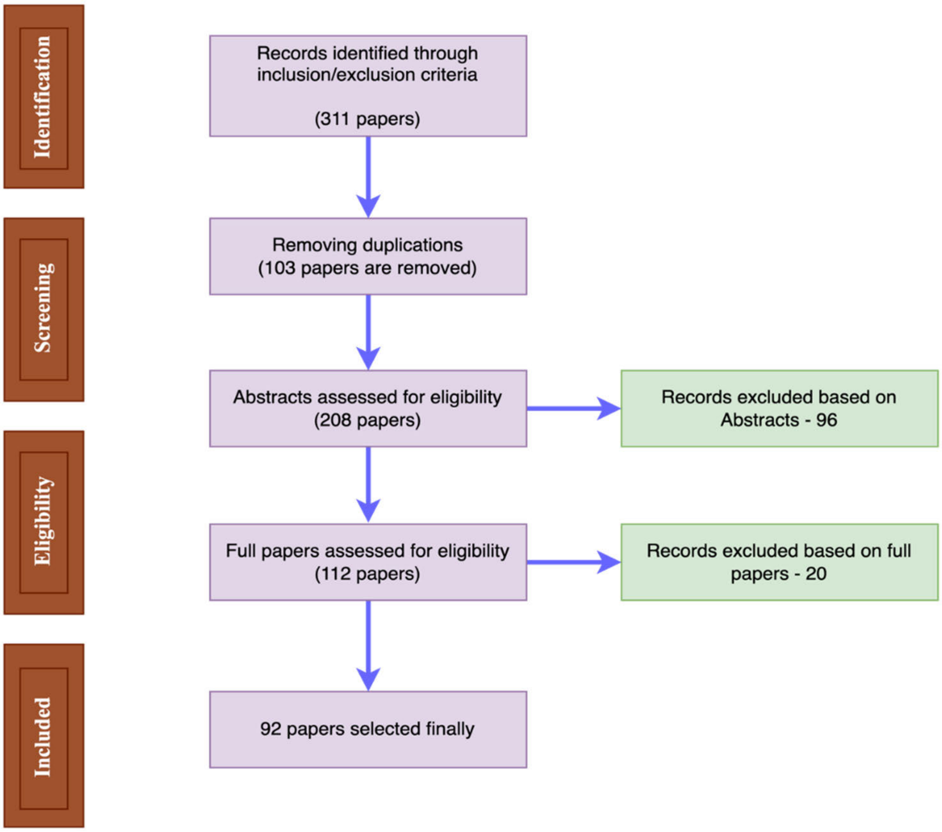

FIGURE 1. **Selection of papers for literature review.**

will ensure food transparency. Bouzembrak et al. [161] mentioned that disintermediation could improve transparency and reduce transaction costs. However, these studies ought to have addressed to what extent human involvement or transport could be reduced with the help of disintermediation.

Data Storage – Due to the complicated structure of the FSC, a significant amount of data is involved, and it is necessary to store this enormous amount of data. Industry 4.0 technologies help store data that can improve traceability, monitoring, and transparency. Our review shows nine studies stated data storage using Industry 4.0 technologies could improve traceability [96], [99], [110], [120], [129], [144], [147], [160], [165], five studies indicated that it can improve monitoring [110], [125], [126], [136], [166] and one study suggested that it can improve transparency [93]. Tayal et al. [96] mentioned that data stored in the blockchain helps with real-time traceability, and Ekren et al. [125] used RFID to store data to improve the monitoring of FSC. But these studies did not investigate the optimal amount of data that could be stored using the technologies.

Accountability – Accountability is accepting responsibility for data in a cloud environment, from data collection to destruction [173]. Our literature review shows that accountability contributes to traceability [99] and cost reduction [110]. Mishra and Maheshwari [99] stated that data accountability helps to identify a person making a scrupulous transaction and can therefore aid traceability. Lin et al. [110] claimed that blockchain reduces transaction costs via better accountability by eliminating middlemen and audit costs. However, these studies are purely qualitative, based on surveys and literature reviews, and do not imply quantitative terms. Furthermore, there needs to be a precise definition for accountability in the above studies.

Immutability – Data stored once and cannot be changed or removed is known as immutable data [174]. Food fraud occurs nowadays due to the numerous food mishaps, and the organisations that cause them may falsify previous data. Traceability and provenance are aided by immutability. We find that three studies showed that immutability improves traceability [95], [96], [111], and two studies stated that it improves provenance [95], [109]. For example, Garaus and Treiblmaier [95] identified that blockchain has the potential to enhance food traceability by providing immutable data throughout the agri-food value chain. Tayal et al. [96] applied TISM (Total Interpretive Structural Modelling) and MICMAC (Cross impact matrix multiplication applied to a classification) analysis to find the key success factors of blockchain and stated that traceability is one of the key success factors that can be improved through immutable data. However, their research input was based on surveys with

TABLE 10. Industry 4.0 technologies used in FSC for visibility & operational efficiency.

Technologies	Studies	Number of Studies
BC	[6], [7], [11], [16], [23], [90], [93]–[121]	35
RFID	[9], [10], [46], [78], [133]–[146]	18
IoT	[31], [122]–[132]	12
BC + IoT	[18], [154]–[159]	7
IoT + RFID	[5], [161]–[162]	3
BD	[151]–[152]	2
ICT	[148]–[149]	2
EC	[147]	1
CC	[150]	1
BC + ICT	[153]	1
BC + EC	[55]	1
BC + RFID	[8]	1
IoT + ML	[48]	1
RFID + ICT	[165]	1
FC + CPS	[166]	1
BC + IoT + RFID	[13]	1
BC + IoT + CC	[12]	1
BC + RFID + EC	[160]	1
IoT + CC + FC	[163]	1
IoT + RFID + ML	[164]	1

convenience sampling methods that cannot be generalised to other parts of the population.

Secure Data – Secured data is free from data security issues, such as information sharing risks, data ownership, data access and storage, and data privileges [175]. Our review identified four studies indicating that secured data can be used for traceability [18], [120], [121], [163], four other papers asserting that secure data can be used for transparency [93], [97], [99], [101] and three studies stating that secure data reduces waste [94], [113], [168]. For example, Khan et al. [18] suggested that safety information is essential for traceable FSCs. Casino et al. [115] presented a novel traceability system with blockchain to overcome the obstacles of traceability mechanisms, such as lack of information and security. Kramer et al. [97] suggested that transparent data can be obtained with a secure data storage solution. However, these studies have not addressed other benefits of secure data, such as how it can reduce recall time and improve customer trust.

Digitalisation – Data digitalisation is the analysis of data collected by devices connected to the internet [121]. Data digitalisation improves traceability, provenance, monitoring,

TABLE 11. *(Continued.)* **Studies that mention industry 4.0 technologies can be used for traceability, provenance, monitoring and transparency.**

Studies	Technology	Themes related to visibility			
		Traceability	Provenance	Monitoring	Transparency
Stranieri *et al.* [93]	BC	✓			✓
Saurabh and Dey [153]	BC, ICT		✓		✓
Tsolakis *et al.* [94]	BC	✓	✓		✓
Garaus and Treiblmaier [95]	BC	✓			✓
Jagtap *et al.* [122]	IoT	✓		✓	
Tayal *et al.* [96]	BC		✓		✓
Kramer *et al.* [97]	BC	✓	✓	✓	✓
Ali *et al.* [98]	BC	✓		✓	✓
Balamurugan *et al.* [154]	BC, IoT	✓			
Majdalawieh *et al.* [155]	BC, IoT			✓	✓
Mishra and Maheshwari [99]	BC	✓			✓
Osei *et al.* [100]	BC	✓			✓
Bhutta and Ahmad [156]	IoT, BC	✓		✓	✓
Cocco *et al.* [101]	BC	✓		✓	✓
Wang *et al.* [183]	BC	✓			
Tharatipyakul and Pongnumkul [103]	BC	✓	✓		✓
Alfred *et al.* [48]	IoT, ML			✓	
Niknejad *et al.* [104]	BC	✓			✓
Rana *et al.* [105]	BC	✓	✓		✓
Tagarakis *et al.* [123]	IoT	✓		✓	
Awan *et al.* [157]	BC, IoT	✓	✓	✓	✓
Sivalakshmi *et al.* [106]	BC				✓
Rejeb *et al.* [31]	IoT	✓		✓	✓
Maity *et al.* [107]	BC	✓			✓
Bergier *et al.* [147]	EC	✓	✓		
Sajja *et al.* [108]	BC	✓	✓	✓	
Tao *et al.* [203]	IoT	✓		✓	
Hu *et al.* [169]	BC, EC	✓		✓	✓
Khan *et al.*[18]	BC, IoT	✓	✓		✓
Prashar *et al.* [90]	BC	✓		✓	✓
Kumar *et al.* [109]	BC		✓	✓	✓
Shahid *et al.* [11]	BC	✓	✓		✓
Zhang *et al.* [167]	BC	✓			
Alfian *et al.* [164]	RFID, IoT, ML	✓			
Lin *et al.* [110]	BC	✓	✓	✓	✓

TABLE 11. ***(Continued.)*** **Studies that mention industry 4.0 technologies can be used for traceability, provenance, monitoring and transparency.**

Balamurugan *et al.* [126]	IoT	✓			
Yadav *et al.* [168]	IoT	✓		✓	
Vodenicharova [148]	ICT	✓			
Behnke and Janssen [111]	BC	✓			✓
Baralla *et al.* [112]	BC	✓	✓	✓	✓
Gai *et al.* [160]	BC, RFID, EC	✓			
Kayikci *et al.* [113]	BC	✓	✓	✓	✓
Kamble *et al.* [114]	BC	✓	✓	✓	✓
Casino *et al.*[115]	BC	✓	✓		✓
Duan *et al.* [23]	BC	✓			✓
Demestichas *et al.* [117]	BC	✓	✓		✓
Feng *et al.* [116]	BC	✓			✓
Kamble *et al.* [158]	BC, IoT	✓		✓	✓
Liu *et al.* [118]	BC				✓
Antonucci *et al.* [16]	BC	✓	✓	✓	✓
Salah *et al.* [6]	BC	✓			✓
George *et al.* [8]	BC, RFID	✓			
Tsang *et al.*[12]	BC, IoT, CC	✓		✓	✓
Bouzembrak *et al.* [161]	RFID, IoT	✓		✓	
Pearson *et al.* [119]	BC	✓	✓		✓
Longo *et al.* [159]	BC, IoT	✓	✓		
Balamurugan *et al.* [128]	IoT	✓		✓	
Allaoui *et al.* [149]	ICT				
Astill *et al.* [13]	BC, RFID, IoT	✓	✓		✓
Jagtap and Rahimifard [129]	IoT	✓		✓	
Casino *et al.* [120]	BC	✓			✓
Fu *et al.* [133]	RFID	✓			
Mao *et al.* [121]	BC	✓			✓
Qian *et al.* [150]	CC	✓			
Liu *et al.* [131]	IoT	✓			
Badia-Melis *et al.* [162]	RFID	✓		✓	✓
Mohammed *et al.* [134]	RFID	✓			
Chen [166]	IoT	✓			
Pigini and Conti [10]	FC, CPS	✓	✓		
Mededjel *et al.* [163]	IoT, CC, FC	✓			
Bottani *et al.* [135]	RFID	✓		✓	
Mohammed *et al.* [136]	RFID	✓		✓	
Alfian *et al.* [137]	RFID	✓		✓	
Giagnocavo *et al.* [152]	BD	✓			
Farooq *et al.* [139]	RFID	✓		✓	✓
Navickas and Gružauskas, [151]	BD	✓			✓
Chen [5]	RFID	✓			
Pang *et al.* [132]	IoT	✓		✓	
Ringsberg and Mirzabeiki [140]	RFID	✓		✓	
Parreño-Marchante *et al.* [9]	RFID	✓		✓	

TABLE 11. *(Continued.)* **Studies that mention industry 4.0 technologies can be used for traceability, provenance, monitoring and transparency.**

Liu *et al.* [141]	RFID	✓			✓
Mainetti *et al.* [182]	RFID	✓			
Wang and Li [78]	RFID	✓			
Hong *et al.* [146]	RFID	✓			

TABLE 12. **Technologies and operational efficiency.**

Studies	Technology used	Themes related to Operational Efficiency		
		Cost reduction	Time reduction	Waste reduction
George *et al.* [8], Prashar *et al.* [90]	Blockchain		✓	
Jagtap and Rahimifard [143]	IoT			✓
Sinha *et al.* [144]	IoT	✓		
Mohammed *et al.* [123]	RFID	✓		
Mohammed and Wang [125]	RFID	✓		
Navickas and Gružauskas [156]	BD	✓	✓	
Pang *et al.* [146]	IoT	✓		
Parreño-Marchante *et al.* [9]	RFID	✓	✓	
Bertolini *et al.* [133]	RFID	✓	✓	
Bertolini *et al.* [132]	RFID			✓
Vlachos [46]	RFID	✓	✓	
Wang and Li [78], Grunow and Piramuthu [134]	RFID	✓		✓

and transparency. Seven studies confirmed that data digitalisation can improve traceability [16], [90], [94], [110], [120], [131], [139], one study indicated that data digitalisation can improve monitoring [129], and four studies indicated that it can improve transparency [16], [98], [155], [168]. For example, Antonucci et al. [16] identified that the digitalisation of blockchain can improve transparency and traceability in the FSC. Japtap et al. [122] introduced a digital and faster approach using IoT devices to monitor food waste generation. These studies are either literature reviews or software architecture developments, but they do not perform any numerical analysis or empirical work to verify how digitalisation can reduce costs or waste.

Reliable Data – This refers to data whose value is within a predefined range depending on their underlying truth [176]. Reliable data are required to forecast demand because food products are perishable, and their consumption is unpredictable. It can be used for traceability, transparency, cost reduction, and waste reduction. Our review found seven studies indicating that reliable data can be used for traceability [8], [11], [12], [93], [100], [141], [146], four studies indicating that it can be used for transparency [12], [121], [141], [156], one study indicating that it can be used to reduce costs [164], and three studies indicate that it can be used to reduce waste [13], [129], [145]. For example, Shahid et al. [11] stated that reliable data is needed to ensure traceability. Tsang et al. [12]

TABLE 13. Features of using industry 4.0 technologies in fsc.

Studies	Technology	Digitalisation	Disintermediation	Storage	Security	Accountability	Reliability	Immutable	Tamper Proof	Integrity	Automation	Compliance	Efficiency
Stranieri *et al.* [93]	BC		✓		✓		✓			✓			✓
Saurabh and Dey [153]	BC, ICT		✓					✓		✓		✓	✓
Tsolakis *et al.* [94]	BC				✓	✓	✓		✓	✓	✓	✓	✓
Garaus and Treiblmaier [95]	BC							✓	✓	✓			
Jagtap *et al.* [122]	IoT	✓		✓									
Tayal *et al.*[96]	BC		✓		✓			✓					✓
Kramer *et al.* [97]	BC		✓				✓	✓	✓		✓		✓
Ali *et al.* [98]	BC		✓		✓			✓					✓
Balamurugan *et al.* [154]	BC, IoT				✓	✓		✓			✓		
Majdalawieh *et al.* [155]	BC, IoT		✓				✓				✓		
Mishra and Mahaeshwari [99]	BC				✓	✓		✓	✓		✓		
Osei *et al.* [100]	BC		✓	✓									
Bhutta and Ahmad [156]	IoT, BC				✓		✓	✓		✓			
Cocco *et al.* [101]	BC			✓	✓		✓	✓	✓		✓		
Wang *et al.* [102]	BC				✓		✓	✓	✓	✓			
Tharatipyakul and Pongnumkul [103]	BC		✓		✓		✓	✓	✓	✓			✓
Alfred *et al.* [48]	IoT, ML			✓									
Niknejad *et al.* [104]	BC	✓		✓	✓		✓	✓	✓	✓			✓
Rana *et al.* [105]	BC			✓	✓	✓		✓	✓				
Tagarakis *et al.* [123]	IoT			✓	✓		✓				✓		✓
Awan *et al.* [157]	BC, IoT		✓	✓	✓				✓		✓		✓
Sivalakshmi *et al.* [106]	BC	✓		✓			✓			✓	✓		✓
Rejeb *et al.* [31]	IoT	✓		✓			✓			✓	✓		✓
Maity *et al.* [107]	BC			✓	✓			✓	✓				
Bergier *et al.* [147]	EC	✓					✓				✓	✓	
Sajja *et al.* [108]	BC				✓			✓	✓				
Tao *et al.* [203]	IoT				✓		✓				✓		
Hu *et al.* [55]	BC, EC		✓	✓	✓			✓	✓		✓		
Khan *et al.* [18]	BC, IoT	✓	✓	✓	✓								
Prashar *et al.* [90]	BC		✓		✓	✓	✓			✓			
Kumar *et al.* [109]	BC		✓		✓			✓	✓	✓	✓	✓	
Shahid *et al.* [11]	BC				✓	✓	✓	✓	✓	✓			✓
Zhang *et al.* [167]	BC				✓		✓		✓				✓
Alfian *et al.* [164]	RFID, IoT, ML				✓								
Lin *et al.* [110]	BC		✓		✓	✓		✓	✓	✓			✓
Balamurugan *et al.* [126]	IoT										✓		

TABLE 13. ***(Continued.)*** **Features of using industry 4.0 technologies in fsc.**

Yadav *et al.* [168]	IoT	✓			✓								
Vodenicharova [148]	ICT												✓
Behnke and Janssen [111]	BC		✓		✓			✓	✓	✓			
Baralla *et al*. [172]	BC		✓		✓		✓	✓	✓	✓			✓
Gai *et al.* [160]	BC, RFID, EC		✓						✓				✓
Kayikci *et al.* [113]	BC		✓		✓		✓	✓					✓
Kamble *et al.* [114]	BC		✓		✓	✓	✓	✓	✓	✓		✓	✓
Casino *et al.* [115]	BC		✓		✓		✓	✓	✓	✓		✓	✓
Duan *et al.* [23]	BC				✓			✓					✓
Demestichas *et al.* [117]	BC				✓			✓	✓				
Feng *et al.* [116]	BC		✓		✓	✓	✓	✓	✓	✓			✓
Kamble *et al.*[114]	BC, IoT			✓	✓						✓		
Liu *et al.* [118]	BC							✓					
Antonucci *et al.* [16]	BC	✓			✓		✓	✓					✓
Salah *et al.* [6]	BC		✓		✓		✓		✓	✓			
George *et al.* [8]	BC, RFID		✓		✓		✓		✓				✓
Tsang *et al.*[12]	BC, IoT, CC	✓			✓		✓			✓			✓
Bouzembrak *et al.* [161]	RFID, IoT			✓	✓				✓				✓
Pearson *et al.* [119]	BC				✓			✓					
Longo *et al.* [159]	BC, IoT				✓			✓	✓				✓
Balamurugan *et al*. [128]	IoT										✓		✓
Allaoui *et al*. [149]	ICT												✓
Astill *et al.* [13]	BC, RFID, IoT		✓		✓	✓		✓			✓		
Jagtap and Rahimifard [129]	IoT	✓					✓				✓		
Casino *et al.* [120]	BC				✓			✓		✓	✓		
Fu *et al.* [133]	RFID	✓									✓		
Mao *et al.* [121]	BC				✓	✓	✓		✓	✓			✓
Qian *et al.* [150]	CC				✓								
Liu *et al.* [131]	IoT								✓	✓			
Badia-Melis *et al.* [162]	RFID			✓	✓					✓			✓
Mohammed, *et al*. [134]	RFID									✓			
Chen [166]	FC, CPS	✓			✓								
Mededjel *et al.* [163]	IoT, CC, FC			✓									
Bottani *et al.* [135]	RFID												✓
Mohammed *et al.* [136]	RFID				✓					✓			
Alfian *et al.* [137]	RFID			✓									✓
Giagnocavo *et al.* [152]	BD				✓							✓	
Farooq *et al.* [139]	RFID				✓					✓			✓
Navickas and Gružauskas, [151]	BD			✓									
Chen [5]	RFID										✓		
Pang *et al.* [132]	IoT				✓								

TABLE 13. ***(Continued.)*** **Features of using industry 4.0 technologies in fsc.**

Ringsberg and Mirzabeiki [140]	RFID				✓								
Parreño-Marchante *et al.* [9]	RFID										✓		✓
Liu *et al.* [141]	RFID				✓		✓						
Mainetti *et al.* [182]	RFID										✓	✓	
Wang and Li [78]	RFID										✓		
Hong *et al.* [146]	RFID						✓				✓		✓

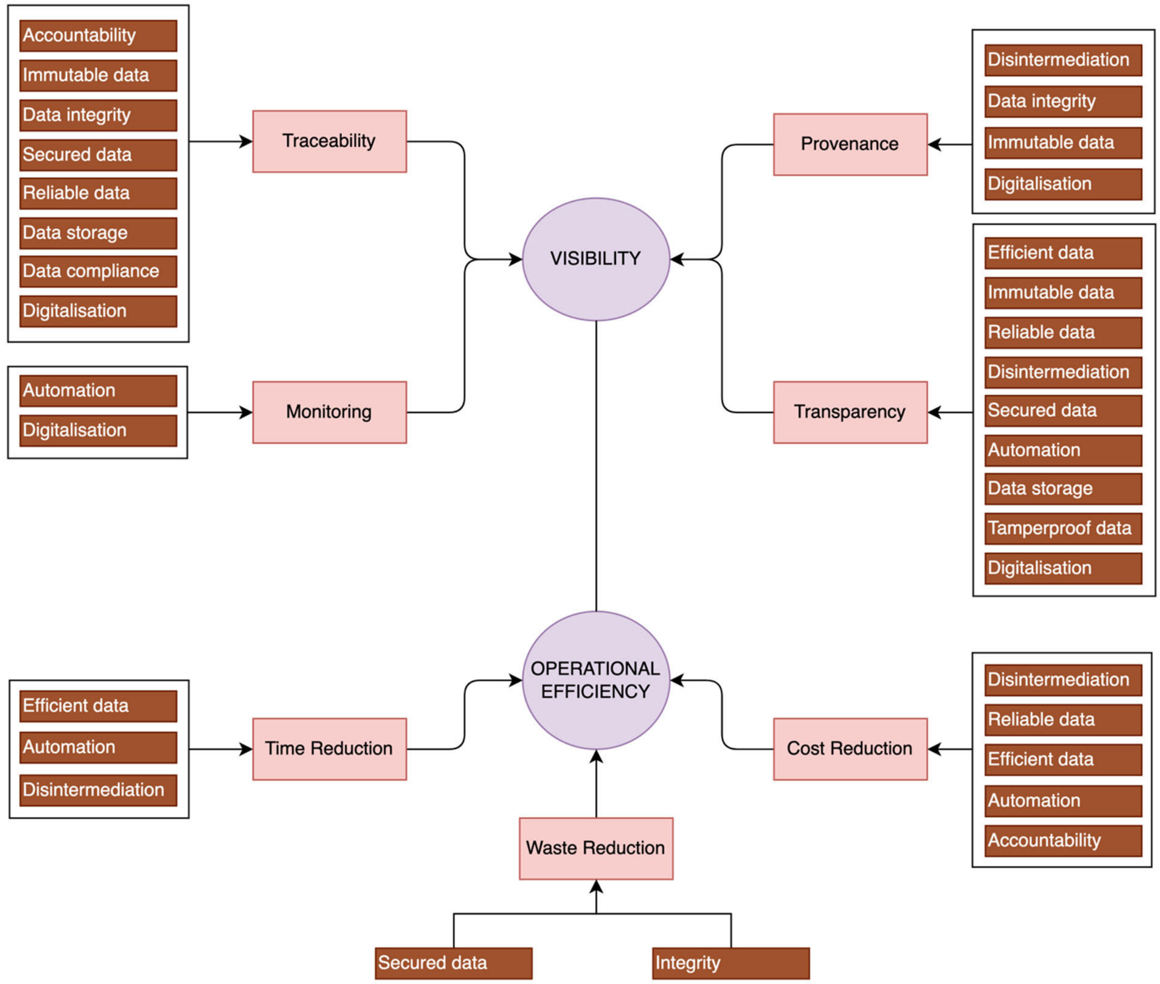

FIGURE 2. **Features of Industry 4.0 leading to visibility & operational efficiency.**

mentioned that reliable data management has the advantage of improved transparency. Similarly, Alfian et al. [164] and Astill et al. [13] concluded that it can reduce costs and waste.

Tamper-proof data – Data that can prevent fraudulent activities are called tamper-proof data [177]. These kinds of data will be needed during food recalls. Our review shows that tamper-proof data can be used for transparency purposes [7], [99]. Zhang et al. [7] suggested that blockchain's tamper-proof features can improve FSC transparency. Similarly, Mishra and Maheshwari [99] proposed a framework that uses blockchain to increase transparency because transactions in the blockchain cannot be tampered with. However, no studies addressed the data retention challenges posed by tamper-proof data.

Data integrity– In integral data, unauthorised data modification is prevented and will always be true [178]. Our study identified three studies that suggested integral data improves traceability [93], [95], [145], two of which stated that integral data improve provenance [94], [112] and three studies indicated that integral data can be used to eliminate waste [31], [94], [162].

TABLE 14. How features of Industry 4.0 lead to visibility and operational efficiency.

Components of Visibility/Operational Efficiency	Features of Industry 4.0	Studies	Number of studies
Traceability	Accountability	[99]	1
	Immutability	[95],[96],[111]	3
	Data integrity	[93], [95], [134]	3
	Secured data	[153] ,[165]	4
	Reliable data	[93], [100], [130],[135]	7
	Data storage	[96],[99],[110],[120],[144],[129],[154],[161],[165]	9
	Data compliance	[5], [9],[93]	3
	Digitalisation	[16], [90], [94], [110], [120], [145], [128]	7
Provenance	Disintermediation	[161]	1
	Data integrity	[94], [172]	2
	Immutability	[95], [109]	2
	Digitalisation	[16], [18], [104]	3
Monitoring	Automation	[5], [9] [136], [138], [125], [126], [128], [163]	8
	Storage	[110],[125], [126],[136]	5
	Digitalisation	[136]	1
Transparency	Efficient data	[94]	1
	Reliable data	[12],[121],[130]	4
	Disintermediation	[94],[111]	2
	Secured data	[93], [97], [99], [101]	4
	Automation	[13], [166]	2
	Data storage	[93]	1
	Tamperproof data	[99],[167]	2
	Digitalisation	[16], [98], [141],[148]	4
Time	Automation	[10], [78], [90]	4
	Disintermediation	[8], [90]	2
	Efficient data	[9], [46], [90], [110], [139], [140]	6
Cost	Accountability	[110]	1
	Reliable data	[164]	1
	Automation	[5], [9]	2
	Disintermediation	[8], [96], [97], [99], [90], [110], [130], [153]	8
	Efficient data	[93], [95]	2
Waste	Data integrity	[31], [94], [163]	3
	Secured data	[94], [168]	2
	Reliable data	[13], [93], [129]	3

Automation– Data can be captured automatically using Industry 4.0 technologies. For example, IoT devices like temperature sensors sense the temperature of the food product and send it to the cloud. This helps in knowing the temperature history of the food product. Our study found that two studies stated automation can help with transparency [13], [164], eight studies suggested it can improve monitoring [5], [9], [124], [129], [136], [137], [139], [166], four studies indicated that it can reduce time [9], [10], [78], [90] and two studies concluded it can reduce overall costs [5], [9]. For example, Alfian et al. [164] used an RFID-based traceability system to ensure food quality and safety because RFID can automatically identify objects. Astill et al. [13] suggested that technologies capable of automating data collection can be used to improve transparency. Similarly, Tao et al. [124] stated that automation of data collection is used to monitor the FSC. Parreño-Marchante et al. [9] mentioned that using RFID for traceability can reduce human errors, labour and operating costs, and time.

Compliance – Compliance means strict adherence to a specific security requirement. Compliant data is organised and can meet pre-specified supply chain rules [179]. These data types can be used for traceability in the FSC. Chen [5] and Parreño-Marchante et al. [9] mentioned that a traceability system compliant across all supply chain entities can generate large amounts of information. Grunow and Piramuthu [145] mentioned that compliance is essential for traceability systems in the FSC.

Data efficiency – Efficiency means how well the resources are used without wastage [180]. We can minimise data loss or inadequacy when Industry 4.0 technologies are used to collect or store data. Our review found one study stating data efficiency can be used for transparency [94], six studies stating it can be used to reduce the time [9], [46], [90], [110], [139], [140] and two studies indicating that it can be used to reduce overall costs [5], [9]. For example, Tsolakis et al. [94] mentioned that food companies greatly appreciate the transparency benefits of implementing blockchain, as the technology allows for efficient data collection. Farooq et al. [139] mentioned that the absence of an effective data entry system increases the time it takes to collect information on contaminated food. Similarly, Garaus and Treiblmaier [95] mentioned that an efficient information system could reduce operating costs.

Given these advantages, it can be inferred that Industry 4.0 technologies have a positive impact on visibility and operational efficiency. However, there is a probability that industries face several challenges while using these technologies. Hence it is also essential to study the challenges of using Industry 4.0.

C. THE CHALLENGES OF USING INDUSTRY 4.0 TECHNOLOGIES IN THE FSC?

Although there are benefits to using Industry 4.0 technologies in the FSC, we also face some challenges when using these technologies. Of all the articles reviewed in this work, most studies talk about challenges such as high costs due to implementation, maintenance, materials, transaction, etc., [13], [94], [114], [153]; high data requirements often found in blockchain as it has low storage capacity and contains immutable data [102], [105], [109], [120]; lack of skills and awareness among stakeholders [13], [18], [94]; complexity due to a large amount of data along with algorithms and codes [95], [158], [161]; energy consumption [12], [55], [109]; low scalability [120], [155]; and regulation [131], [155], [161]. Table 15 presents the challenges discussed in the existing publications with references. Figure 3 highlights the challenges an FSC faces when technologies are implemented. These challenges are detailed as follows:

High Costs: The participants in an FSC are dispersed throughout the world. Because of this, the total cost of technology implementation, infrastructure, maintenance, etc., will be very high. Other variable expenses exist as well, depending on the technology used. Blockchain, for instance, comprises the cost of mining; RFID, the cost of tokens; and so forth. Some entities will not be eager to contribute to the enormous cost of integrating new technologies into their supply chain.

Low Data Storage: FSC contains large amounts of data, but this is beyond the capabilities of some technologies. Large data storage in such technologies is either not possible or very expensive. For example, EC devices only need to store data from local devices and have much less storage capacity.

Lack of Skills and Awareness: Farmers are the primary producers in an FSC. Most farmers are not educated and will not have the knowledge or skills to use cutting-edge technologies. As a result, they refuse to deploy the technologies in their supply chains. Apart from this, small food retailers also lack awareness of these technologies among supply chain entities.

Lack of Trust: Although Industry 4.0 technologies are used for data storage, it cannot be ensured that the data entered by the entities are valid. As food items are perishable, the entities are expected to enter false data to sell their product even if it deteriorates. Hence, more trust among the entities will be needed while using the technologies.

Complex Networks: Some Industry 4.0 technologies contain complex algorithms and computations to process data. For example, smart contracts in blockchain involve algorithms; data mining in ML and AI involves complex computations. Hence complex networks are involved, which further requires skilled personnel.

High Energy Consumption: Industry 4.0 technologies consume large amounts of energy. It will consume power for processing as well as data transmission. Farmers and food retailers will not be able to support such high energy use. This further increases the overall cost.

Low Scalability: Scalability is the process of maintaining the system's performance as the environment changes. The food market fluctuates frequently and is entirely unpredictable. The complexity of Industry 4.0 technologies will increase due to such systemic developments.

Regulations: Different countries have different regulations for using technologies. Therefore, it is challenging to adopt certain technologies in these countries. For example, cryptocurrencies are banned in some countries. Therefore, it is not possible for the utter usage of the advantages of blockchain

FIGURE 3. Challenges of using Industry 4.0 Technologies.

or smart contracts. MENA countries (Middle East and North Africa) impose certain restrictions on the use of IoT devices.

Different FSC entities face different challenges while implementing Industry 4.0 technologies, and the vigour of the challenge will be different for all the entities. Since not all entities would experience the same cost-to-benefit ratio, some entities may be less inclined to adopt these technologies. Thus, if the technologies are to be employed throughout the supply chain, there should be a cost-sharing among the entities. The technology cost-sharing mechanism in an FSC must thus be studied.

D. HOW CAN TECHNOLOGY COSTS BE SHARED AMONG VARIOUS ENTITIES OF THE FSC?

Some of the main advantages of using Industry 4.0 technologies in the FSC are data storage, access, transmission, and backup. All entities, from farm to fork, store data in storage devices. However, the responsibility or ownership of technology lies mainly with retailers like Walmart and Amazon [8]. In most FSCs, a third party is responsible for the technology, and the primary entities collect data from them [129], [130]. The amount of data varies between entities. As the amount of data increases, so does the cost. Therefore, the sharing cost of an entity can be based on the amount of data they store in the system.

The cost-sharing of technology can be analysed according to product freshness and the product selling price of each stakeholder. For example, Liu et al. [118] studied the issue of investment decisions in the green agri-food supply chain. This study used a factor, the cost optimisation coefficient and found that the sum of the retailer's and producer's investment costs depends on the retailer, the sale cost of the producer, and freshness. Fu et al. [133] applied game theory in the fresh produce supply chain to study RFID investment decisions and analyse the RFID investment decisions of retailers. Their findings yielded two important insights regarding RFID investment: (1) when the investment costs are not significantly high, RFID should be invested by the retailer under the control strategy or manufacturers under the delegation strategy, (2) sometimes under the delegation strategy, the retailer can profit from the manufacturer's RFID investment.

Smart contracts may be implemented when blockchains are used for the FSC. The usage and implementation of smart contracts will have a transaction cost (for example, in the Ethereum blockchain, the cost of smart contracts is directly affected by the amount of gas consumed [184]). Thus, the blockchain cost can be shared among stakeholders based on the number of transactions each stakeholder performs. Food processing plants and retailers typically have a high volume of transactions compared to other entities. Alternatively, the computational cost while using blockchain can be measured in terms of the number of transactions [185]. Just as the computation of stakeholders increases, so will their percentage share. Figure 4 shows several cost-sharing

TABLE 15. Challenges of using Industry 4.0 technologies in FSC.

High cost	BC	[8], [12], [13], [94], [95], [103], [105], [113], [114], [117], [119], [153], [181]
	IoT	[12], [13], [31], [122], [123], [124], [158], [161], [164]
	ML	[165]
	ICT	[148], [153]
	RFID	[8], [9], [13], [139], [140], [141], [161], [162], [164],
	CC	[12], [150]
Large data storage	BC	[8], [12], [13], [102], [105], [109]–[112], [114], [116], [119]–[121]
	IoT	[12], [13]
	RFID	[8], [13]
	CC	[12]
Lack of skills	BC	[18], [23], [94], [95], [96], [97], [98], [99], [100], [103], [110], [113], [117], [155], [159]
	IoT	[18], [122], [155], [159], [161]
	RFID	[13], [162], [182]
Lack of awareness	BC	[13], [18], [23], [55], [100], [103], [113], [159]
	IoT	[13], [18], [31]
	EC	[55]
	RFID	[9], [13]
	BD	[152]
Lack of trust	BC	[12], [13], [18], [23], [99], [103]
	IoT	[12], [13], [18], [159], [163]
	RFID	[13]
	CC	[12], [163]
	FC	[163]
Complex networks	BC	[16], [23], [90], [95], [97], [98], [103], [105], [108], [113],[114], [117], [159], [161]
	IoT	[122], [158], [159], [161]
	RFID	[146], [161], [182]
High energy consumption	BC	[12], [16], [55], [94], [97], [98], [100], [105], [109], [110], [114], [117]
	IoT	[12], [132]
	EC	[55]
	CC	[12]
Low scalability	BC	[6], [11], [12], [23], [94], [96], [102], [103], [105], [110], [113], [115]–[117], [119], [120], [155]
	IoT	[155]
Regulations	BC	[6], [16], [23], [96], [99], [110], [113], [116], [117], [119], [155], [158], [183]
	IoT	[31], [131], [155], [161]

mechanisms between entities in the FSC using Industry 4.0 technologies. For example, when RFID is used, the cost of the technology can be shared based on the number of RFID tags an entity holds. Similarly, when IoT is used, costs can be shared based on the number of IoT devices an entity owns.

Very few studies address the cost-sharing mechanisms in the FSCs and the supply chains in general when using

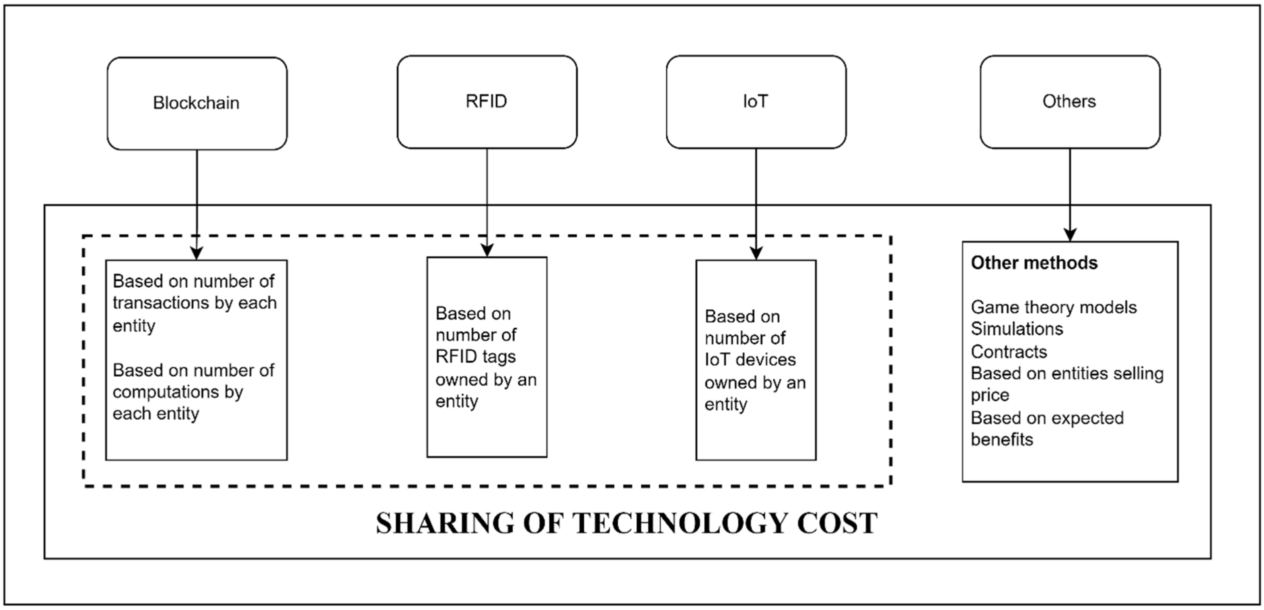

FIGURE 4. **Cost-sharing mechanisms while using Industry 4.0 technologies.**

technologies. This area is vital, as it will motivate supply chain entities to implement technologies in their supply chains and improve coordination between them. In addition, each entity can predict its own share of technology costs and can therefore decide on whether to implement the technology or not.

V. DISCUSSION

This study provides a content analysis- based LR on how Industry 4.0 technologies are used in the FSCs. Ninety-two papers were reviewed to find the features, benefits, and challenges related to an FSC's visibility and operational efficiency while using Industry 4.0 technologies. This section discusses the inferences that can be drawn from the findings in the previous section.

A. IMPACT OF INDUSTRY 4.0 TECHNOLOGIES IN THE FSC

From the benefits of these technologies presented in the previous sections, it can be concluded that Industry 4.0 technologies positively impact visibility and operational efficiency in the FSC. Existing studies have yet to address how to improve - the visibility and operational efficiency of the FSC using AI, AM, AR, VR, robotics, and CgC. Nevertheless, these technologies are used in other industries. This section sheds light on how these unexplored technologies can find their use in the FSC. Most FSC data are unstructured. Information mining techniques using AI can certainly solve the challenges of unstructured data [186]. AI can reduce recall costs in the FSC and improve traceability by optimising multi-objective models [187]. AI with blockchain in the FSC will improve trust, cooperation and traceability [113].

Another technology, AM, can simplify food packaging, which is one of the key FSC processes. Thomas [50] discussed the costs, benefits, and application of AM in the supply chain and also mentioned that in the supply chain, the unit cost of AM is higher than that with traditional methods; however, it can reduce the cost of designing complex products, for example, food. The time, labour or natural resources required to use these complex products can be reduced, but stakeholders need additional skills.

In most cases, the FSC entities are geographically located far apart. Therefore, it is difficult for all entities to know the condition of the storage, trucks etc. For this, FSCs can use VR, which can help in digitalisation by simulating a warehouse's appearance and getting information on bottlenecks, production analysis, storage, vehicle requirements etc. This is possible even when the entities are thousands of miles apart. As a result, FSCs can exploit the benefits of AI, VR, and AM to improve visibility and operational efficiency in the FSC. Duong et al. [188] discussed the application of robots in the food industry from a supply chain perspective. They mentioned that robots and autonomous systems can improve worker's cognitive abilities and provide accurate supply chain analysis. FSCs can improve their operational efficiency by using ML, which helps entities predict and solve complex problems. ML algorithms help entities to get significant insights from the available data.

B. CHALLENGES OF USING INDUSTRY 4.0 TECHNOLOGIES

Several challenges related to the use of Industry 4.0 technology are presented in section IV. Some courses of action should be taken to overcome these challenges. The farmers are the primary suppliers in an FSC, and farmers in developing nations like India lack education. The entities of the FSCs can be upskilled to use these technologies. Organisations must develop a good awareness of advanced and cutting-edge technologies, that can be done with the help of news articles, magazines etc.

Governments can relax regulations on the deployment of Industry 4.0 technologies. They can also subsidise energy costs because of the high energy consumption in some of these technologies. This is important because different countries have different regulations regarding the use of technology, and these regulations present a significant challenge for technology implementations. For example, countries like Algeria, Nepal, and Bangladesh have banned the cryptocurrency Bitcoin, used for blockchain transactions. In addition, countries such as North Korea and Saudi Arabia have either limited or expensive internet access. Therefore, it is not easy to use technologies in countries with strict regulations on the use of technologies.

Most of the specified Industry 4.0 technologies have complex networks. Proper infrastructure needs to be developed for the smooth use of these technologies, especially in developing countries like India, where the agricultural sector significantly contributes to the country's economy. Some stakeholders refuse to use technologies in their supply chains due to a lack of trust. Proper accountability of data should be maintained among the stakeholders to improve trust.

Although most technologies are expensive, as given in Table 15, they can reduce certain costs. For example, RFID can reduce investment costs [134]. In addition, this technology will prevent inventory shrinkage and inaccuracies [135] and thus can minimise the associated costs. The IoT execution has certain issues like high cost and energy consumption, but it can increase the market share and reduce inventory [127]. The implementation of smart contracts also faces cost issues, but knowing how to solve this issue is still in its infancy. However, iOlite, a start-up company featured in blockchain, solves this problem by using their Fast Adaptation Engine (FAE), which does not charge for developing smart contracts.

C. COST OF SHARING TECHNOLOGY

Finding the right partners is very important in an FSC. We find that in most FSCs a third party is assigned to the operation of technology, and the primary entities only retrieve data from them. Therefore, a fraction of the profits is given to these third parties. For example, Walmart builds a blockchain-based food traceability system with the help of its technology partner IBM. If the entities of the supply chains are up-skilled in using technologies, the profits can be shared among the entities themselves.

AI and ML can be used to predict demand, as the food industry faces huge demand uncertainty. When utilising AI or ML, organisations can share costs in accordance with the intended use of the technology. The downstream companies should pay more for the technology if it is used for predictive analysis, such as to forecast demand to prevent interruptions in supply and demand. This is because the downstream entities experience greater supply chain uncertainty. Upstream entities should pay more if these technologies enhance the quality of the food product because the upstream entities bear a greater responsibility for quality. In the case of cloud computing, there can be two ways of sharing the cost. If each entity has their own cloud, then the cost sharing can be done based on the usage or the resources they consume. If a centralised entity maintains the cloud, they can track the usage, consolidate the cost and distribute the expenses among the entities. The usage also depends on the storage space, computing hours, data transfer, etc.

Supply chain entities have the option to integrate long-term agreements for a joint investment of equipment expenses, as is often observed in the cases of IoT, AR, VR, AM, EC and robotics. If RFID is used, we can apply a tag cost sharing mechanism. Gaukler et al. [189] states that sharing the tag cost will lead to a higher profit when the retailer is the supply chain leader. However, tag cost sharing does not affect the profit if manufacturer is the supply chain leader. Tao et al. [190] found a threshold value for tag cost sharing rate below which the retailer should invest in RFID, else the manufacturer has to invest in RFID. These kinds of tag cost sharing mechanisms can be applied for FSC as well.

Several contracts can also be used to share technology costs. For example, through revenue sharing, retailers can share with manufacturers a percentage of revenue generated by technologies. Similarly, buyback and quantity flexibility contracts can also be used. However, due to high uncertainty in an FSC, using the same contract for every order may create a huge loss in some cases. Therefore, a potential future work is to find the best supply chain contract for each order using data from the technologies. In addition, it is also necessary to figure out who will be responsible for the operation of the technology so that supply chain profits can be maximised. Subscription-based costing models can be developed where one entity owns the technology and other entities pay the subscription fee to use it.

The entities must also share other costs, such as implementation, infrastructure, and maintenance costs. These costs vary for different technologies. As a result, studies can be done that list the costs associated with each technology. Therefore, entities in the supply chain should have a clear idea of the technology they will use before implementing it. Existing literature lacks these types of cost-sharing mechanisms.

VI. RESEARCH GAPS & FUTURE DIRECTIONS

The research gaps and future directions identified based on our research questions are outlined in the following subsections.

A. PERTAINING TO FEATURES AND BENEFITS

We have seen the benefits of Industry 4.0 technologies, which improve visibility and operational efficiency in the FSC. Most previous literature on the FSC focuses on designing a framework or software system to enhance these benefits, but there needs to be more empirical or quantitative research on these benefits. Therefore, quantifying these benefits by performing numerical or empirical studies can help with cost–benefit analysis in the FSC and so could be an excellent future area of research. This can be done using linear or non-linear optimisation methods. Genetic algorithms, simulated annealing, etc., are some dominant optimisation methods. Meta-heuristics or simulations can also be performed to develop a cost–benefit analysis. The automation properties of these technologies can be used to form self-adaptive FSCs. In self-adaptive FSCs, the objects learn, design, and operate themselves continuously [191]. Therefore, implementing self-adaptive systems in the FSC can be a good direction for the future. In addition, using these technologies to meet the challenges posed by climate conditions is also a good area for future study.

Previous literature lacks in finding the optimum demand and supply of perishable items. In addition, works related to proper shelf and store replenishment that reduce waste are also scarce. Shelf replenishment is moving products from the back room to the shelves to refill the inventory, and store replenishment is moving products from warehouses, suppliers, manufacturers etc., to fill store inventory [192]. Hence, some studies should be done on demand–supply trade-off, shelf replenishment, and store replenishment by exploiting the benefits of Industry 4.0. Blockchain can be used for decentralisation, but this can lead to a lack of trust as entities can pass on false information about food products. Applying game theory mechanisms to encourage entities to share factual information about food products is also an interesting area for future research. Nash bargaining solution, ultimatum game etc., are some game theory methods that can be used for this purpose.

There need to be more studies on using stochastic modelling to optimise cost, time, and waste in an FSC. The introduction of stochastic models to calculate the operational efficiency of an FSC is a good area for future research. Maity et al. [107] analysed a stochastic model to find how the increase in the number of blocks can improve the tamper resistance of the data. This type of quantitative or numerical analysis can be performed for other features listed in Table 14. Several studies mention that these technologies reduce various costs like inventory, recalls etc. [31], [94], [123]. As another direction for future research, it is possible to quantitatively assess the overall impact of these technologies in terms of costs since quantitative approaches are more objective and generalisable.

Among the technologies considered in this study, previous FSC research needed to have practical and effective use of AI, AM, AR, VR and CgC. Therefore, implementing these technologies in the FSC will be a tremendous future direction. Technologies such as CC, FC, EC, ICT, ML, and CPS are mentioned in very few studies. Hence, there needs to be more research on these technologies. This is likely due to these technologies' high costs and complex calculations. However, these technologies can also substantially improve the visibility and operational efficiency of the FSC. For example, CC supports centralised large-scale data storage. FC or EC offers distributed computing and storage platform by offloading computing load. EC devices and ML can be used to extract data. AM can be used to personalise food products. Foodini is used as a 3D printer to print food-related products. Thus, we can impose postponement processes in the FSC, i.e., delaying the final production of the product to improve customisation. This technology can also be used for packaging food products. Therefore, using AM in the FSC to reduce time and waste is also a good direction in the future.

B. PERTAINING TO CHALLENGES

While there are many benefits to using Industry 4.0 technologies, firms face several challenges when using these technologies, which are presented in Table 15. Every technology has its own challenges. In such a case, two or more technologies can be combined to gain more benefits so that the benefits of one can overcome the challenges of the other. For example, data automation characteristics of IoT helps to capture data and send it to the blockchain. Thus, manual entry into the blockchain can be avoided.

Previous literature has shown the benefits of combining technologies, but only a few studies have implemented more than one technology. For example, Wamba and Queiroz [193] stated the advantages and importance of combining blockchain with AI and IoT in an FSC but still need to implement it. They claimed that IoT automation and AI data mining features, combined with blockchain, can further improve trust and traceability in the supply chain. This eliminates the need for trust and complex network challenges in the blockchain. ML can be combined with RFID to filter out false positives and detect outliers [164]. These further increase trusts.

Since blockchain involves solving complex computations, ML can be combined with blockchain to solve these computations, reducing the work of miners. Therefore, deploying more than one technology in the FSC to overcome the challenge could be a good future direction. A proof of concept or artefact combining two or more technologies can be developed to further improve the FSC.

Lightweight blockchains can be used to avoid high computing power and complex network. The lightweight blockchain is a modified version of the blockchain with simplified algorithms without compromising data security. It can also significantly reduce computing power [194]. Reducing network complexity using lightweight blockchain in the FSC could be a good future area of study.

Another challenge of some Industry 4.0 technologies is the low storage capacity. EC devices that will store information in edges and send only relevant information to the cloud can reduce the amount of data that needs to be stored. Hence, using EC with low data storage capacity technologies can be a good future scope. As a matter of fact, latency can be considered an essential metric in the FSC, but very few studies have mentioned this term. Calculating latency during data transfer can clarify delay and hence the operational efficiency. Therefore, this can be a good future scope.

C. PERTAINING TO COST-SHARING

The cost of sharing technology should be a strategic decision in the FSC. There is a lack of literature related to the cost of sharing the technology. Ghouri and Mani [195] addressed

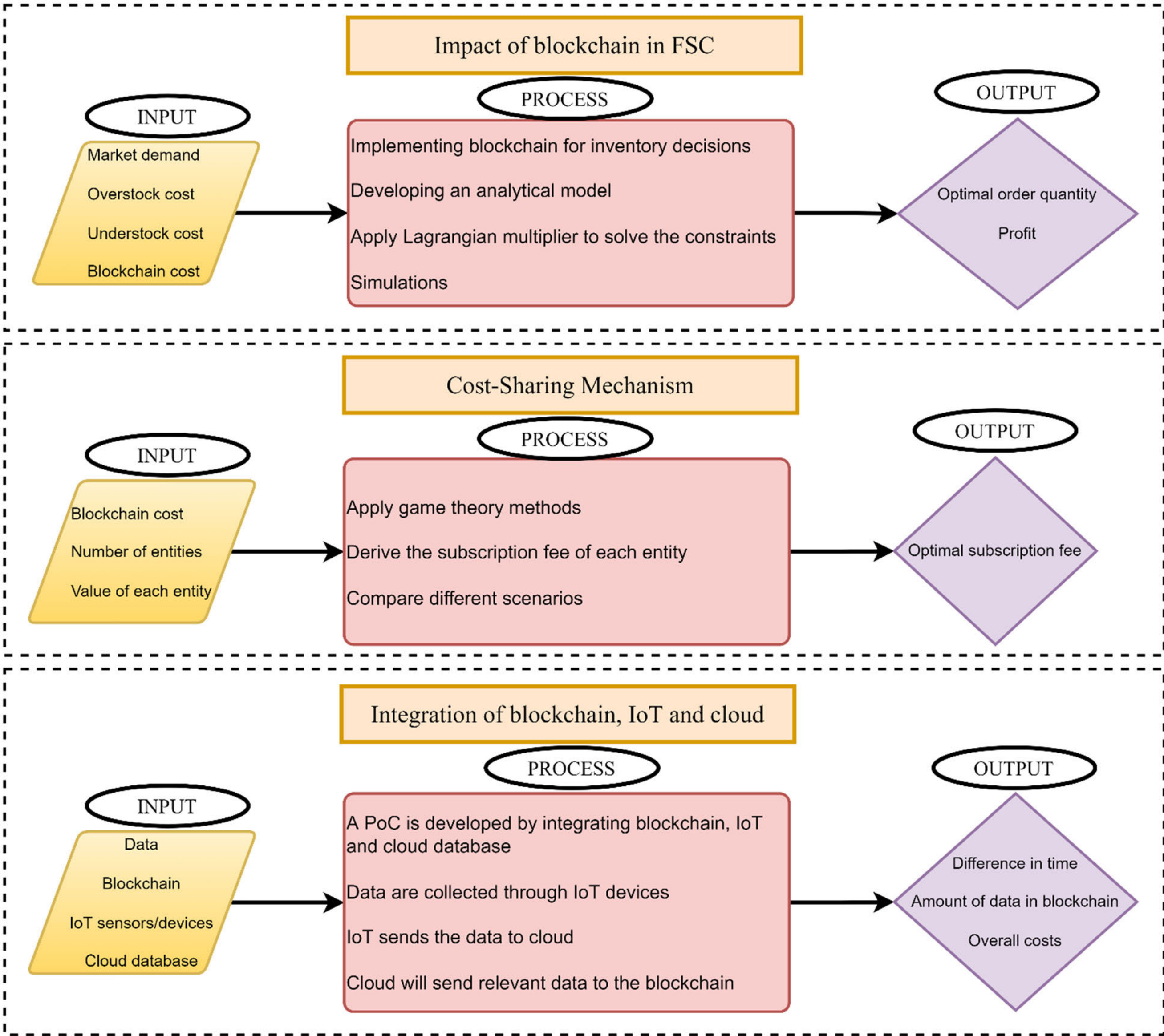

FIGURE 5. Proposed conceptual framework.

the perception of middle-level managers on modern technologies. They focused more on information sharing and purchase behaviour but did not bring up the picture of sharing the technology cost. Technology costs can be shared between members of the supply chain based on the expected benefits of each member. For example, in Ustundag [196], the cost of RFID tags is shared among the supply chain members according to their expected benefits. These kinds of techniques are not followed in the FSC.

Simulations can be performed to check the optimum share of each supply chain member, as simulations can be used to calculate the expected benefits. For example, Kang and Gershwin [197] used simulations to highlight shrinkage in inventory, resulting in lost sales when the items become unexpectedly out of stock. Lee et al. [198] investigated the effect of inventory accuracy on inventory reduction using simulations in a three-echelon supply chain.

Smart contracts, when used in a blockchain for transactions, the cost of the technology can be shared based on the number of transactions because transaction costs increase with the number of transactions [199]. Technology costs can also be shared based on the number of devices owned by each supply chain member. As the number of devices owned by an entity increases, the costs associated with implementation, maintenance, etc., will increase. As a result, other variable costs associated with the use of technology can be spent on other entities. For example, Chen et al. [200] studied the incentives for RFID adoption by varying fixed costs of

TABLE 16. Validity & validity threats.

Sl No.	Type of validity	Features	Action	Validity satisfied / Validity threat
1	Construct	Venue	We have not selected any specific venue. This study is taken all around the world. Hence, there is no bias in venue selection.	No validity threat in the venue
		Search string	We have taken appropriate search strings for visibility and operational efficiency in the FSC.	No validity threat in the search string
		Search methods	We have done both automatic as well as manual searches. Some papers are excluded after reading the abstracts and full papers.	There is no validity threat in search methods
		Inclusion and exclusion criteria	The inclusion and exclusion criteria are relevant to the research questions.	There is no validity threat in inclusion and exclusion criteria
		Research questions	We have formed appropriate research questions with justifications.	There is no validity threat in forming research questions.
2	Internal	Sample size	The number of studies taken for this SLR is 92, which is a reasonable number for an SLR in FSC.	There is no validity threat in sample size.
		Publication bias	We have selected only journal publications.	There is a validity threat in the publication selection as we did not include grey articles.
		Standard languages	Here, RFID and IoT are considered separately as the works related to RFID in FSC are significantly higher than other IoT technologies. Same can be said for AI and ML.	It means we have applied different terms for identical concepts. Hence, there is a validity threat.
3	External	Timespan	The time span of this study is only from 2011 to 2021.	As we are considering only eleven years, there is a validity threat.
		Incomplete research information	The objective of this SLR is clearly explained. The data extraction and justification for each research question are also clearly explained.	No validity threat in this case
4	Conclusion	Data extraction bias	The data extraction for each research question is clearly explained. Also, two authors performed the manual search independently.	No validity threat in this case
		Identifying errors in primary studies	The primary search is related to traceability, provenance, monitoring and transparency as these are very common. Also, for operational efficiency, we considered only cost, time and waste. There can be other subsets/parameters also.	As we have considered only four parameters for visibility and three for operational efficiency, there can be a validity threat.

supply chain entities. Wang et al. [201] proposed a technology investment decision model to reduce potential costs in the FSC. Here, the investment levels of manufacturers and suppliers in technology depend on the reputation and amount of contaminated products of the respective parties. Another popular method that can be used for cost-sharing mechanisms is game theory. This is a branch of applied mathematics where two or more parties make decisions based on the possible decisions of other players. These methods can be used to find the optimal share that each entity in the FSC must share in order to utilise the technologies in their supply chain.

D. PROPOSED FRAMEWORK

This section presents a proposed conceptual framework which is a part of our future work. This will lead to a novel cost-sharing mechanism and a Proof of Concept (PoC) using blockchain, IoT, and cloud. Figure 5 shows the proposed conceptual framework for our future work. To know the impact of Industry 4.0 on the FSC, an analytical model will be developed to show the impact of demand, time, cost and transparency in the supply chain when blockchain is implemented. Blockchain is chosen as it is one of the most widely used technologies in the FSC for traceability, transparency, provenance, monitoring, and operational efficiency. As a cutting-edge technology, it is an area that is being actively researched and of great interest to the industry due to its special features, such as cryptocurrency, immutability, and smart contracts. Lagrangian multipliers technique and simulations will be used to find the optimum values of the parameters like price, time, and order quantity. They will be compared to non-blockchain instances.

To find a way to share technology costs between entities, a subscription-based cost-sharing mechanism will be developed to share blockchain costs between supply chain entities. A subscription fee will be derived for each entity. Different scenarios of who bears the cost of the technology will be compared. For example, if a manufacturer incurs technology costs, the subscription costs of other entities to be paid to the manufacturer will be found. Game theory methods like the ultimatum game and Nash bargaining models with asymmetric information will be used for this. Simulations will be performed to compare the different scenarios.

To meet the challenges of Industry 4.0 technologies, we can integrate two or more technologies so that one can overcome the challenges of the other. In our study, we will integrate blockchain, IoT, and CC. IoT devices will trace all possible data like product temperature, lead time, etc. and send them to the cloud. The cloud will send only relevant data to the blockchain, which are used for visibility. In this case, IoT can be used for automation, the cloud can be used to reduce the amount of data in the blockchain, and blockchain can be used for immutable and tamper-proof data. This is a part of our future work, and the experts in the FSC will validate it by taking feedback or conducting interviews. We will also conduct a case study to assess the validity of future work.

VII. LIMITATION OF THE STUDY

One of the limitations of this study is that it only focused on journal publications. Including grey literature will further strengthen the review and be an excellent future work. Also, studies in English were only included in our review. Considering the studies from non-English languages will further improve the study.

Another area for improvement is that the initial search for studies related to visibility is based only on traceability, provenance, monitoring, and transparency. Bringing in more visible components can yield more accurate results. Furthermore, we only consider 16 technologies as they are the most used in the previous literature. The findings could be more eclectic if all Industry 4.0 technologies are considered. Also, this study does not contain any empirical analysis, and hence much importance is not given to the objectivity of the findings. However, we took inputs from about 200 papers, which we believe is sufficient to overcome this limitation. We have also found the validity and validity threats to describe further limitations of this study. Table 16 presents the validity and validity threats of this study. The features are taken from Zhou et al. [202], who identified some validity threats in the SLRs published from 2004 to 2015.

VIII. CONCLUSION

Food contamination has become a severe problem in recent years. Customers are willing to buy safe products even if it costs more than usual. There is a need for a change in the traditional FSC by implementing technologies to ensure food quality, make decisions, obtain accurate data and for many other purposes. This indicates the importance of visibility and operational efficiency in the FSC. Hence, this paper has put forward a content analysis-based literature review to study the impact of Industry 4.0 technologies on the FSC's visibility and operational efficiency.

Our content analysis clarifies the importance of Industry 4.0 technologies in the FSC. We have presented a list of the most used Industry 4.0 technologies, and only these technologies are considered for this study. Industry 4.0 technologies used to date in the FSC to improve visibility and operational efficiency are also found. Of the 92 studies reviewed, 53% of articles discussed blockchain, 30% RFID, and 32% IoT. Therefore, blockchain, IoT and RFID can be considered as the most promising technologies to date that can improve visibility and operational efficiency in the FSC. Other technologies used so far are EC, BD, ML, CPS, CC, FC, and information and communication technologies (ICT). Existing FSC studies have not used AI, AR, AM, VR, robotics, and CgC. We have also seen how these underutilised technologies can be used in the future for FSCs. Besides traceability, provenance, monitoring and transparency, some of the features of Industry 4.0 technology in the FSC related to data and operational efficiency are also presented. Given these benefits, it can be concluded that Industry 4.0 technologies can improve the visibility and operational efficiency of the FSC.

Some of the challenges addressed in existing publications are also presented. Although most technologies are expensive, the benefits of these technologies can reduce certain costs, such as costs for intermediaries, costs of delays and human errors, and inventory costs. Two or more technologies can be combined to gain more advantages so that the advantages of one can overcome the challenges of another. Finally, some future directions, limitations of this study, validity, and threats to validity were also discussed. As a conjecture, this is the best time for the food manufacturers and other entities of FSC to implement Industry 4.0 technologies, which can also be an initial input for implementing Industry 5.0 when it reaches the market.

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VASANTHRAJ received the master's degree in industrial engineering.

He is a Research Scholar with the Department of Management Studies, Indian Institute of Technology Madras, India. He is also a joint doctoral program student at Curtin University. His research interests include supply chain management, operations management, cost sharing in the supply chain, and technologies in the supply chain. Also, he has previous experience working as a teaching assistant for NPTEL courses, an online learning platform in India.

ARSHINDER KAUR received the Ph.D. degree from IIT Delhi, India.

She is a Professor of operations and supply chain at the Department of Management Studies, Indian Institute of Technology Madras, India. She has worked at Curtin University, Australia, and has been visiting the University of Passau and Hof University, Germany, as a Guest Faculty. She has got an honorary appointment as a Key Technology Partner Visiting Fellow with the UTS Business School, University of Technology Sydney, Australia, in May 2017. Her research interests include supply chain coordination, sustainable supply chain, digital supply chain, inventory control, service management, and strategic sourcing. Her research has appeared in refereed journals (more than 40 articles) such as *Omega*, *International Journal of Production Economics*, *Computers & Industrial Engineering*, *International Transactions in Operational Research*, *Journal of Cleaner Production*, *Benchmarking: An International Journal, Journal of Knowledge Management*, and *International Journal of Logistics Research and Application*. Her doctoral work (Ph.D. thesis) on the topic "Supply Chain Coordination" has been accepted as a Highly Commended Award Winner of the 2008 Emerald/EFMD Outstanding Doctoral Research Award. She is a reviewer of many reputed international journals, such as *European Journal of Operational Research*, *International Journal of Production Research*, *Production Planning and Control*, and *Applied Mathematical Modeling*.

VIDYASAGAR POTDAR is currently the Director of the Blockchain Research and Development Laboratory (BRDL), Curtin University, Perth, Australia, where he leads a 15-member Research and Development Team that focuses on delivering commercial blockchain solutions to industry and government. In the last two years, the Blockchain Laboratory has led and successfully delivered 12 blockchain projects in Australia across a variety of industries, including agriculture, sustainability, mining, art, healthcare, supply chain, photography, and recycling.

He is also an Adjunct Professor at the Symbiosis Institute of Technology, Symbiosis International University, Pune, India. Furthermore, a multi-award-winning researcher, who has published over 160 articles, supervised more than 20 Ph.D. students, and raised over $3 million in research funds.

HIMANSHU AGRAWAL received the Ph.D. degree from RMIT University.

He is currently a Lecturer with the School of Electrical Engineering, Computing and Mathematical Sciences, Curtin University. His research interest includes the Internet of Things, edge or fog computing, blockchains, artificial intelligence, machine learning, and cybersecurity. He received the Outstanding Reviewer Award for the *Journal of Network and Computer Applications*, in 2016.