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REVIEW ARTICLE

The role of internet of things in food supply chain quality management: A review

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ABSTRACT
In their review of internet of things (IoT) applications in supply chain management, Ben-Daya et al. identified the food supply chain (FSC) as one of the application areas with greatest potential for reaping the benefits of IoT. In this paper, we focus on the FSC, conduct a literature review, and carry out a bibliometric analysis in order to better understand the potential, challenges and role of IoT and other enabling technologies such as blockchain on FSC quality management. Most of the literature focuses on the technology aspects in providing solutions to FSC challenges. The review also indicates that the literature dealing with models and decision support systems that make use of IoT data to enhance the decision-making process is limited. This is clear from the limited number of publications in operations management and related journals that usually deal with these issues. Based on the findings of this literature review, we provide possible research topics that take advantage of the rapid technological advances in the area of FSC.

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Introduction

The fierce competition in today's markets due to globalization has been forcing companies to increase their competitiveness to survive in such a complex environment. Companies have realized that effective quality management (QM) and supply chain management (SCM) are key success factors that play an important role in the strengthening of organizational competitiveness (Talib, Rahman, and Qureshi 2011; Foster Jr 2008).

QM is a management philosophy that has been embraced by many organizations as an important approach to achieve a competitive advantage since the 1980s. However, initially, QM was focused on the internal view of quality dealing with the management of production processes and products to provide adequate product design and features according to customers' expectations (Sousa and Voss 2002; Mellat-Parast 2013). With the increase in supply chain globalization and decentralization of production, it was realized that taking full advantage of the potential of QM requires paying equal importance to upstream and downstream supply chain processes. Product quality depends not only on the quality process of the manufacturer but also on the quality process of its suppliers (Fernandes et al. 2017) and the understanding of the needs of the customers.

SCM is another source of competitive advantage that can help firms deal effectively with today's global and challenging environment. Individual businesses cannot compete as independent entities but rather as active members of the wider supply chain involving a network of multiple businesses and relationships (Lambert and Cooper 2000). Competitiveness can be achieved through operational efficiency and service quality that will deal with challenges and managing opportunities all over the supply chain.

Therefore, QM is an effective means to support SC activities through ensuring continuous performance improvement throughout the SC leading to higher levels of customer satisfaction. However, this requires QM to not be limited to internal processes but to also include upstream and downstream processes (Zeng, Phan, and Matsui 2013). Upstream QM initiatives include long-term relationships with suppliers, supplier involvement in product development and quality improvement, and supplier selection and certification with a focus on quality. Downstream QM activities include frequent meetings with customers or surveys to understand customers' needs, seeking customer feedback on quality issues, and customer involvement

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in product design, among other activities. What is even more important, is the seamless coordination between QM processes across the supply chain.

Supply chain quality management (SCQM) is a more recent development that advocates the importance of integrating QM and SCM. Robinson and Malhotra (2005) stated that SCQM "is the formal coordination and integration of business processes involving all partner organization in the supply channel to measure, analyze and continually improve products, services, and processes to create value and achieve the satisfaction of intermediate and final customers in the marketplace."

From a general perspective, SCQM has been considered as a systems-based approach to performance improvement that creates a synergy between QM and SCM best practices to leverage opportunities created by upstream and downstream relationships with suppliers and customers (Foster Jr 2007). Its success hinges on the cooperation of supply chain partners and their commitment to improving processes, services, products and work cultures to achieve total customer value and satisfaction (Ross 1998). There is evidence through several studies that there is a positive relationship between SCQM practices and overall organizational performance (Lin et al. 2005; Azar, Kahnali, and Taghavi 2010; Soares, Soltani, and Liao 2017).

SCQM is particularly important in the food supply chain (FSC). Compared to traditional supply chains, FSC brings additional challenges. FSCs deal with perishable products with limited shelf-life that may have serious safety issues for consumers. This has two implications: (i) a lot of food is wasted along the supply chain; (ii) concerns about food safety.

Approximately one-third of the food produced globally for human consumption does not reach the end consumer because it is either lost or wasted along with the various points in the FSC (Gustavsson et al. 2011). The magnitude of the problem is astounding as 1.6 billion tons of food, equivalent to an estimated worth of $1.2 trillion, is lost or wasted worldwide on an annual basis. Moreover, with the issue mounting incessantly, the yearly food loss and waste is estimated to grow to 2.1 billion tons of food – worth about $1.5 trillion by the year 2030. Additionally, about 8% of the global emissions of greenhouse gases (GHGs) can be attributed to food loss and waste (Hengsholt et al. 2018). Therefore, this issue is of paramount importance and there is a dire need to address it to enhance food quality and safety, combat hunger, and reduce its economic and ecological impact (Gustavsson et al. 2011).

Given the growing consumer concerns about food safety in recent years, both the food industry and the public authorities are developing quality and safety assurance systems. Experts believe that the safety concerns posed by the food-borne disease will increase in the future because of many reasons such as changes in climate, microbiological systems, water supplies, urbanization, and the increase in food trade worldwide (Käferstein and Abdussalam 1999). To deal with these challenges there is a need for developing adequate monitoring and traceability systems for FSCs.

In terms of quality management systems, FSC companies rely on food-centric systems (Fiorino et al. 2019). The most known standards in the broad ambit of food and packaging producers at least include (BRC 2018; FSSC 2017; IFS 2017; ISO 2018; RSPO 2014; SQF 2017):

- The Global Standard for Food Safety (GSFS) by the British Retail Consortium (BRC)
- The International Featured Standard (IFS) Food, by the IFS
- The ISO 22000 norm, by the ISO
- The Food Safety System Certification (FSSC) 22000
- The Safe Quality Food (SQF) by the SQF Institute, USA
- The Roundtable on Sustainable Palm Oil (RSPO) certification scheme.

The common denominator of these systems is the partial or total adherence of the chosen procedures and instructions to basic principles of the Hazard Analysis and Critical Control Points (HACCP) (Fiorino et al. 2019). The structure of these food quality systems is based on the following pillars: (i) The commitment of senior management (ii) The trend and research for continuous amelioration (iii) The elaboration; development and improvement of the 'food safety plan'; (iv) Internal audits; nonconformities and preventive/corrective actions; (v) The evaluation and re-assessment of raw material suppliers; (vi) Traceability; (vii) Layout design, flow charts, processing operations and segregation; (viii) Sanification and site hygiene; (ix) Allergen risk management and genetically modified organism risks; (x) Training and safety culture.

Information technology (IT) has been and continues to be an essential enabler for effective supply chain management (SCM) (Ross 2016). IT has made a major impact on SCM due to its capability for internal integration of various processes and more importantly external integration with suppliers and customers. This has been achieved through improving communication, acquiring and transmitting data, thus enabling effective decision making and enhancing supply chain performance.

Internet of Things (IoT) is a new IT revolution providing a paradigm shift in several areas including SCM. IoT takes supply chain communications to another level: the possibility of human- to-things communication and autonomous coordination among "things" while being stored in a facility or being transported between different supply chain entities (Ben-Daya, Hassini, and Bahroun 2019b). IoT provides new levels of supply chain visibility, agility and adaptability to cope with various SCM challenges (Ellis, Morris, and Santagate 2015). The data emitted from smart objects, when effectively collected, analyzed and turned into useful information, can offer unprecedented visibility into all aspects of the supply chain, providing early warnings of internal and external situations that require remediation. Responding to these signals in time can drive new levels of supply chain efficiency.

This is particularly important in the FSC as IoT will allow reducing the time between data capture and decision making. This enables supply chains to react to changes in real-time and reduces food waste. In addition, it allows for quick action in case of recalls or safety concerns. IoT will also enable remote management of supply chain operations, including after-sales services and maintenance, better coordination with partners, faster tracking and tracing, and can provide more accurate information for more effective decision-making.

The purpose of this paper is to provide an informative review of the role of IoT and related enabling technologies such as blockchains on SCQM in the FSC. Ben-Daya, Hassini, and Bahroun (2019b) reviewed the literature on the applications of the internet of things in supply chain management. They identified the FSC as an area of great potential for IoT applications. In this paper, we focus on the FSC to understand its specific characteristics, challenges and the role of IoT and related enabling technologies on improving the performance of such chains.

The bibliometric analysis and literature review conducted indicate that the literature dealing with models and decision support systems that make use of IoT data to enhance the decision making process is limited. This is clear from the limited number of publications in operations management and related journals that usually deal with these issues. Based on the findings of this literature review we provide possible research topics that take advantage of the rapid technological advances in the area of FSC.

The remainder of this paper is organized as follows. Section "Food supply chain quality management" presents an overview of SCQM in the context of FSCs highlighting key issues and characteristics of such an environment. Key IT technologies that can help meet the challenges of the FSC are discussed in Section "Enabling technologies". The review methodology and a summary of the literature through a bibliometric analysis are presented in Section "Methodology and bibliometric analysis" and the literature review is the object of Section "Main findings of the literature review". Section "Discussion and future research directions" contains a discussion of key findings and identifies future research directions.

Food supply chain quality management

Food supply chain characteristics

The FSC encompasses the processes of food production, processing, distribution, consumption and disposal. Compared to other supply chains, FSCs have special characteristics that make them far more complex to manage. In this section, we provide a brief discussion of these characteristics.

Most FSC products are perishable and have limited shelf-life that affects their quality. Shelf life is defined as "*the period that the decreasing quality of perishables remains acceptable for end-users*" (Taylor, Shewfelt, and Prussia 1993). Consequently, food product quality is also defined differently from durable products. It deals with the overall acceptance of food and can be described by subjective attributes such as aroma, firmness, color and taste. The main fact that differentiates food supply chains from other chains is that there is a continuous change in the quality from the time the raw materials leave the grower to the time the product reaches the consumer (Apaiah et al. 2005). Food quality changes due to chemical or biochemical reactions. These reactions are affected by various factors, both intrinsic and extrinsic (Lin, Negenborn, and Lodewijks 2015). In particular, food quality is determined by time and environmental conditions such as temperature, humidity and the presence of contaminants. Controlling these conditions affects the rate of internal reactions and therefore the decay process. Quality attributes are indicators of these internal reactions. Such attributes should be monitored during warehousing and transportation to minimize waste and safety risks.

Also, there are several uncertainties related to food products in terms of variability of quality and yield of supply inputs, seasonality, and long lead time of production. Variability in process yield and quality is due to biological variations and random factors related to weather, pests and other biological risks.

FSC challenges

Due to globalization and rapid urbanization, FSCs extend over wide geographical areas to feed growing urban populations. The increased cross-border flow of livestock and food products, and international cooperation and partnerships, add to the complexity of FSC management.

Customers are more and more demanding in terms of quality, integrity, safety, sustainability and associated information services (Van der Vorst, Van Kooten, and Luning 2011). Safety in particular is a crucial issue in the FSC. The Codex Alimentarius Commission (CAC 2003) defines food safety as an assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use. The continuing sequence of food incidents requiring massive product recalls are increasing consumer concerns about food safety. Several high profile product safety events and recalls have increased public attention to food safety and security (Marucheck et al. 2011; Gorton and Stasiewicz 2017). These incidents include the horsemeat scandal (The Guardian 2019), the China milk scare (Fairclough 2008) and the E. coli outbreak (WHO 2011). In June 2006, Cadbury withdrew a million chocolate bars, which were contaminated by a rare strain of salmonella (BBC 2006).

Sustainability in terms of waste and GHG emissions related to the business processes in the supply chain network is another major challenge for the FSC. As mentioned earlier, about one-third of the food produced is wasted (Gustavsson et al. 2011). The globally extended supply chains are increasing the number of miles a product travels before it reaches the consumer (food miles). As a result, food products account for an important part of the emissions produced during production, warehousing and transportation. The extremely high waste of food products and their high carbon footprint are a major concern to all supply chain entities.

The question now is how the FSC can address these challenges to reduce waste, ensure consumer safety, and improve FSC performance and sustainability. This is discussed in the next section.

Implications of FSC challenges

As discussed earlier, a major FSC challenge is keeping food safe and controlling its quality as it moves through the supply chain. The quality of food is dependent on how food products are handled at every touchpoint throughout the FSC. Proper management of the flow of FSC products requires a high level of visibility and effective means of traceability.

Ben-Daya, Hassini, and Bahroun (2019a) define supply chain visibility as "*the ability of a firm to collect, access, assess and share useful, accurate, trusted, secure and timely information across its internal functions as well as the supply chain partners and market.*" Visibility and transparency throughout the FSC can play a key role in dealing with quality and waste issues. Visibility provides the information required for effective and timely decision making throughout the FSC. For example, with real-time information on food quality, supply chain partners can share the information and be able to take actions to control quality rather than passively react to the deterioration of food products.

Traceability is a key principle of quality management and another important concept that can address the food safety issue. To ensure safety, the FSC needs a faster response to food scandals and incidents. Good traceability systems will minimize the adverse effects of the production and distribution of unsafe or poor quality products, thereby minimizing the potential for excessive recalls, bad publicity, and liability. In addition to safety concerns, consumers also demand verifiable evidence of traceability of provenance as an important criterion of food quality and safety.

Visibility and traceability require the collection of timely information and the sharing of information and collaboration between various FSC partners. These issues are discussed in the next section.

Need for real-time information

Both supply chain visibility and traceability can benefit from various enabling technologies such as IoT and blockchain to better manage the FSC to improve quality and reduce waste. Visibility can be achieved through real-time monitoring and tracking of food products location and conditions (e.g., temperature and humidity) throughout the supply chain. For example, a cold chain, which is an uninterrupted-temperature controlled transport and storage system of refrigerated goods between upstream suppliers and consumers (Montanari 2008; Taoukis et al. 2016, pp.285–309), can benefit from real-time monitoring and control of food quality. Unexpected temperature changes or tampering in the food cold chain can lead to compromised food safety and food quality that ultimately can result in a loss of consumer confidence and increased levels of food waste.

A real-time temperature monitoring system can be defined as one having the ability to check, measure, and report the actual temperature at any time (Ndraha et al. 2018). Effective temperature monitoring will help the food business operators in making decisions, taking corrective action, and improving their operation. For example, Shih and Wang (2016) proposed a cold chain system based on IoT technology. The real-time collection of data using IoT technology at each point of the cold chain using radio frequency identification (RFID) tags increased annual sales and reduced energy consumption.

IoT and other enabling technologies have great potential for enhanced levels of control of the FSC. IoT is expected to revolutionize the FSC because it allows for (Sundmaeker et al. 2016):

- Better sensing and monitoring of production, including farm resource use, crop development, animal behavior and food processing;
- A better understanding of the specific farming conditions, such as weather and environmental conditions, animal welfare, the emergence of pests, weeds and diseases, and the creation of knowledge about appropriate management actions;
- More sophisticated and remote control of farms, processing and logistics operations by actuators and robots, e.g., precise application of pesticides and fertilizers, robots for automatic weeding, or remote control of ambient conditions during transportation;
- Improving food quality monitoring and traceability by remotely controlling the location and conditions of shipments and products;
- Increasing consumer awareness of sustainability and health issues by personalized nutrition, wearables and demotics.

IoT and several enabling technologies are available to enhance FSC management. Some of these technologies are specific to the FSC. These areas discussed in the next section.

Enabling technologies

Modern global food supply chains are facing many challenges. The most important one is food waste, which is estimated at 30% of the total human food production and can reach 50% for fresh fruit and vegetables due mainly to a lack of temperature control (Pang, Chen, and Zheng 2011; Gustavsson et al. 2011; FAO 2013; Hundy, Trott, and Welch 2016; Badia-Melis et al. 2018).

With global, highly distributed and heterogeneous food supply chains, the classical packaging and identification approaches are not enough to meet the new regulatory requirements along with increased customers' awareness about food integrity. Indeed, with global food supply chains, the need for food safety and traceability has dramatically increased (Coulomb 2008; Badia-Melis et al. 2018).

Traditional packaging is nowadays being replaced by active and intelligent packaging (Ghaani et al. 2016). Active packaging consists of including in the package some active material, such as oxygen scavengers or moisture regulators, to extend the produce's shelf life. Intelligent packaging incorporates materials that will monitor the quality of the food such as devices to control temperature (Ghaani et al. 2016).

Also, traditional identification approaches such as barcodes are not sufficient to ensure food quality monitoring and traceability and are more and more replaced by RFID tags and wireless sensors networks (WSN) (Costa et al. 2013; Badia-Melis, Mishra, and Ruiz-García 2015a).

The application of the RFID and WSN technology in food monitoring and traceability systems are multiple and varied (Badia-Melis, Mishra, and Ruiz-García 2015a). RFID technology is more reliable and efficient than classical barcodes or quick response (QR) codes as it provides a higher reading rate (Hong et al. 2011). In addition, it allows the identification of the products without physical contact, which enables efficient customization and handling (Zhang and Li 2012).

RFID tags or wireless sensors are usually placed in pallets or batches to indicate the location and provide information about the temperature, the humidity, the presence of gases and the occurrence of acceleration from vibration and shocks (Badia-Melis et al. 2018). However, the implementation of such systems still faces many challenges due mainly to the high system cost (Badia-Melis et al. 2013) in addition to the harsh conditions under which the sensors have to function (such as humidity, rain, temperature) (Lee et al. 2010).

Multiple other approaches are emerging to ensure the safety, quality and traceability of food products. New technological trends in food quality monitoring, food traceability and smart packaging are summarized in Table 1.

The recent technological advancement in the food supply chain can significantly help in increasing food

Table 1. Summary of enabling technologies for FSC quality management.

Function	Technology	Source
Food quality monitoring	Temperature estimation:	Badia-Melis et al. (2013)
	• Capacitors • Kirging • Artificial intelligence	Jedermann, Ruiz-Garcia, and Lang (2009); Uysal, Emond, and Bennett (2011); Jedermann et al. (2011); Badia-Melis et al. (2013); Badia-Melis, Mc Carthy, and Uysal (2016)
	Thermal imaging	Badia-Melis et al. (2017, 2018)
	Computational fluid dynamics (CFD)	Delele et al. (2013); Defraeye et al. (2014); Berry et al. (2016); Han et al. (2017); Badia-Melis et al. (2018)
Traceability	Near field communication (NFC)	Mainetti, Patrono, and Vergallo (2012); Mainetti et al. (2013a)
	Blockchain	Galvez, Mejuto, and Simal-Gandara (2018)
	Isotope analysis and deoxyribonucleic acid (DNA) barcoding	Becker, Hanner, and Steinke (2011); Cai et al. (2011); De Mattia et al. (2011); Galimberti et al. (2013); Arcuri et al. (2013); Badia-Melis, Mishra, and Ruiz-García (2015a)
	Chemometrics and Near-infrared spectroscopy	Vandeginste (2013)
Smart packaging	Time and Temperature indicators (TTI)	Taoukis and Labuza (2003); Yam, Takhistov, and Miltz (2005); Ghaani et al. (2016)
	Freshness indicators	Smolander et al. (2002); Siro (2012); Kuswandi et al. (2014); Heising, van Boekel, and Dekker (2015)
	Gas indicators	Mills (2005); Yam, Takhistov, and Miltz (2005)
	Nanotechnology and nanosensors	Brody, Zhuang, and Han (2010); Duncan (2011); Jornet and Akyildiz (2012); Ramachandraiah, Han, and Chin (2015); Fuertes et al. (2016)
	Biosensors and gas sensors	Kerry, O'Grady, and Hogan (2006); Wang (2006); Ghaani et al. (2016)

quality integrity and at the same time reduce food waste. However, the high diversity in the products, the processes, and the logistics routes make it difficult to find a unique well-adapted solution to all situations. Therefore, a combination of different technologies should be adopted on a case-by-case approach (Badia-Melis et al. 2018).

In practice, many challenges face the implementation of these technologies at a larger scale. First, the cost of RFID tags is more expensive than barcodes. This has restricted its implementation to high-value products (Ping et al. 2018). Besides, temperature estimation methods can help in reducing the number of needed temperature sensors (Badia-Melis et al. 2018). Second, a large amount of data is generated by IoT devices to control and monitor food supply chains that impacts the hardware cost and saturates the communication bandwidth through WSN. Third, the information security of the data collected by IoT devices represents an important challenge. In addition to these problems, the lack of standardization in IoT systems can lead to difficult interconnections between different systems, platforms and standards. Finally, a new generation of sensors more adapted to the food environment should be developed. Indeed, there is a need for rapid detection sensors that are capable to resist a harsh environment (Ping et al. 2018).

Methodology and bibliometric analysis

Research methodology

Rowley and Slack (2004) proposed a methodology to conduct a literature review, which includes scanning documents, making notes, structuring the literature review, writing the literature review, and building the bibliography. In this paper, we followed their approach and we augmented it with a structured bibliometric and network (citation and co-citation) analysis following the approach adopted by Mishra et al. (2016).

Defining keywords search

The main selected keywords for this research are "IoT", "quality", "supply chain" and "food supply chain". We have searched using three combinations of these keywords: (1) "quality AND supply AND chain", (2) "IoT AND quality AND supply AND chain" and (3) "IoT AND quality AND food AND supply AND chain".

Initial search results

The data was collected from the Scopus database, the largest abstract and citation database having over 20,000 peer-reviewed journals from Elsevier, Emerald, Informs, Taylor and Francis, Springer and Inderscience, and covering the fields of science, technology, medicine, social sciences, and arts and humanities (Fahimnia, Sarkis, and Davarzani 2015). Web of Science (Wos) is another potential database that we could have used. Based on our experience with bibliometric analysis for journal articles, both Scopus and WoS lead to similar analysis. Given that Scopus includes a larger database, we opted for using it in our search.

Using the "All Fields" search in Scopus database, we collected and stored journal articles, conference papers, chapters of books, and review papers for the aforementioned keywords search terms resulting in

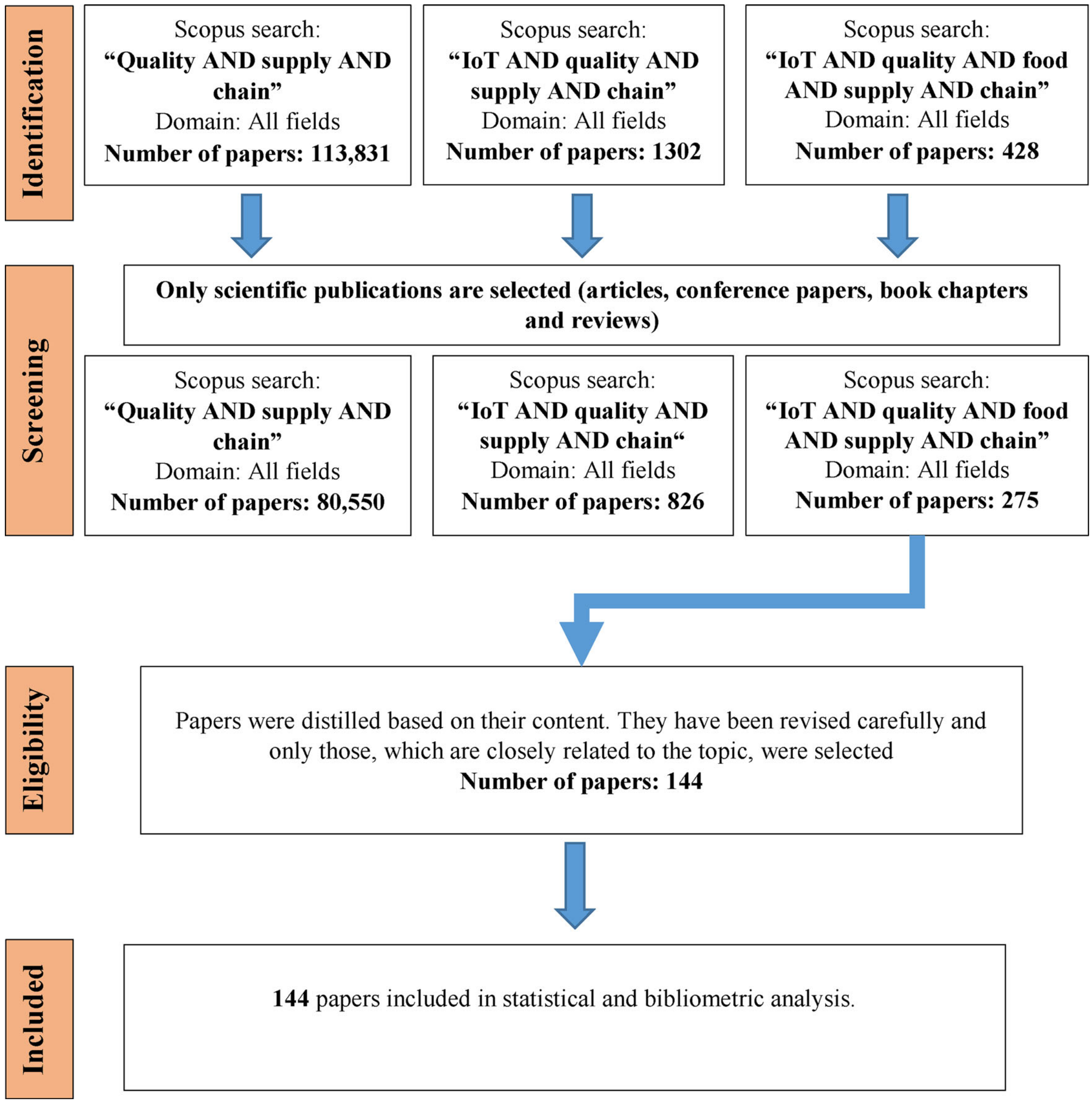

Figure 1. Research methodology.

113,831, 1302, and 428 documents for each of the search combinations, respectively.

Refinement of the search results

We refined our initial search by excluding those, which appear in more than one combination of keywords and restricted the search to only scientific publications (articles, conference papers and reviews) that appeared in peer-reviewed journals. Also, we restricted the date range to publications that were published during 2005–2019. The last search was done in February 2019. We decided to start our search in 2005 as that is where the interest in the application of technology that is the precursor to IoT, such as RFID, started to gain speed in the supply chain management field. This first refinement resulted in 80,550, 826, and 275 documents in each search combination, respectively.

Given our focus on the role of IoT in FSC quality, we have further distilled the 275 publications obtained from the search based on the third combination of keywords. A laborious and manual reading of the papers' content is carried to identify those that are relevant to our review topic. We noticed that many papers mentioned all the search keywords but did not focus on the role of IoT in food supply chain quality management. We only kept the papers that are relevant to our topic. We ended up with 144 relevant articles. The flow diagram of Figure 1 details the different steps of the papers' selection.

Initial data statistics

In Figure 2, we show the time distribution of the 144 selected publications. Taking into account the possible lag in recent publications, we can see that there is a clear

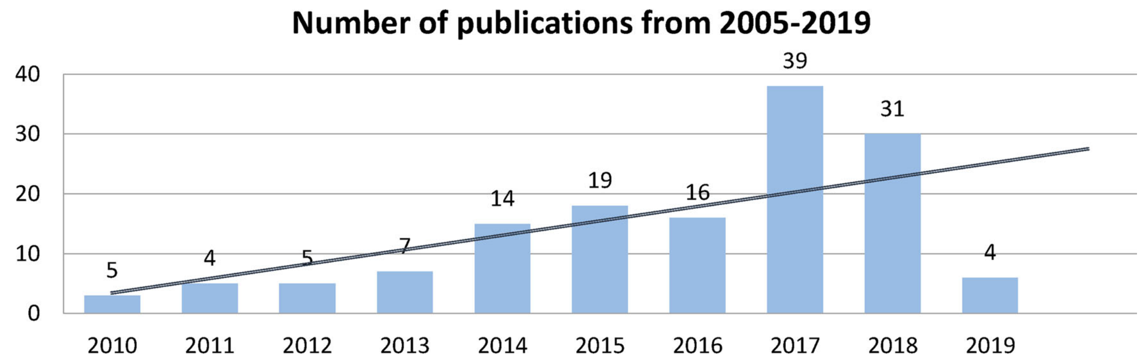

Figure 2. Time distribution of reviewed publications.

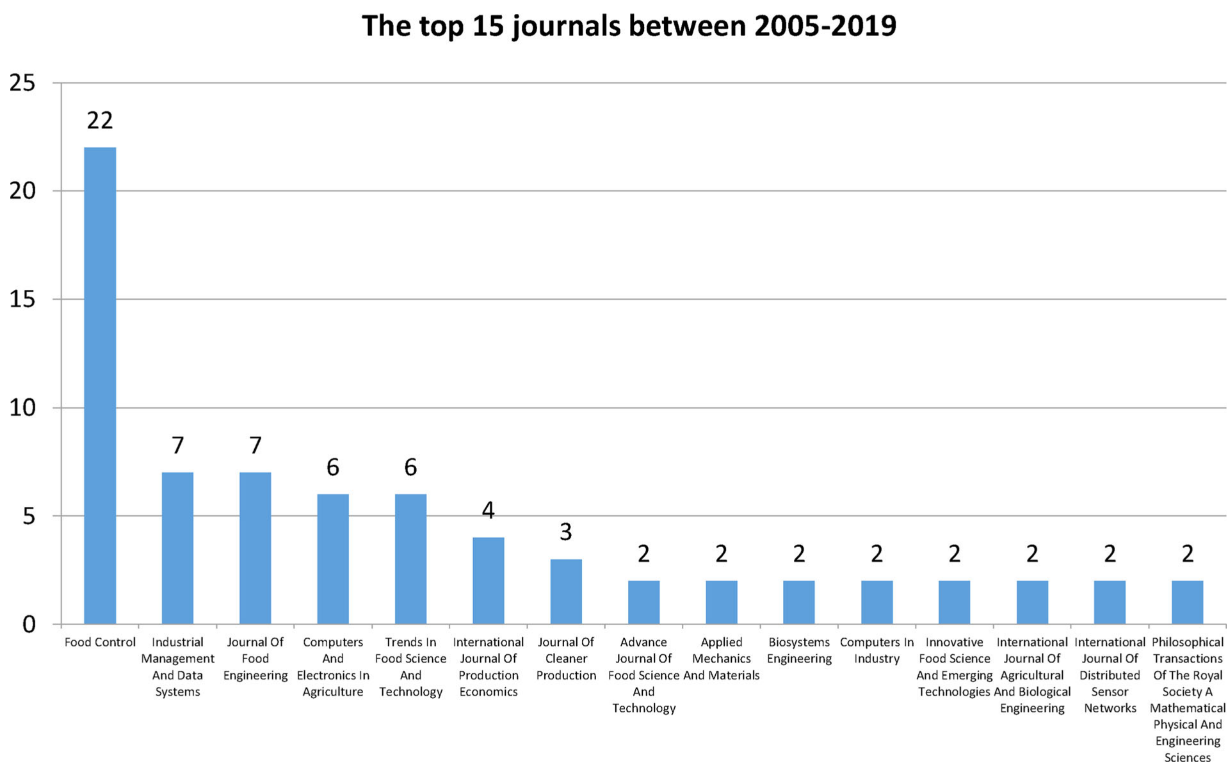

Figure 3. Frequency distribution of the top 15 journals appearing in our search database.

increasing trend in the number of publications. This indicates the increasing interest in FSCM research.

There is a total of 70 different journal sources for our review database. In Figure 3, we show the frequency distribution of the top 15 journals with the most articles that appeared in our review database. We observe that the food science journals dominate the list with 41 articles or 58% of articles appearing in the top 15 journals. On the other hand, we note that there are only 14 articles in production and operation management-related journals (7 in Industrial Management and Data Systems, 4 in International Journal of Production Economics and 3 in Journal of Cleaner Production), or 20% of articles appearing in the top 15 journals. This finding has motivated us to develop this review as a means to introduce more operations and production management researchers to this challenging and important area of research.

Data analysis

In this section, we analyze the reviewed papers and their cited references using bibliometric and network analysis tools.

Bibliometric analysis

Bibliometric analysis is an attempt to quantitatively assess the academic quality of journals or authors by statistical methods such as citation rates. In our analysis, we focused on information regarding authors, title, journal, publication year, keywords, affiliations, category and type of contribution. Several software

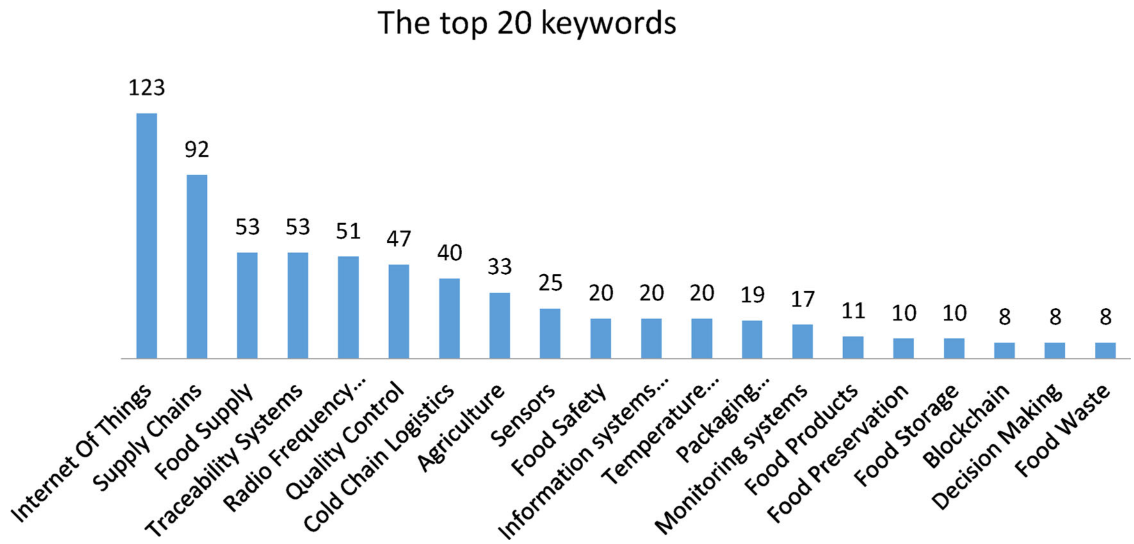

Figure 4. The top 20 common keywords.

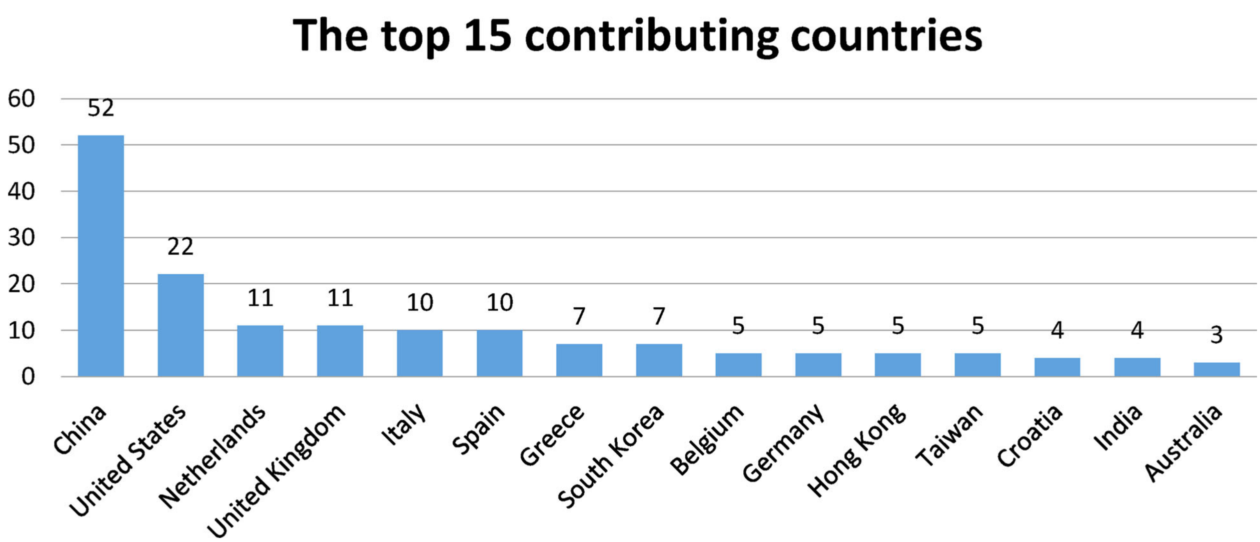

Figure 5. Top 15 contributing countries.

tools can aid in conducting bibliometric studies. In this study, we used BibExcel due to its flexibility to work with large datasets and the compatibility with different computer applications including Excel, Pajek and Gephi (Persson, Danell, and Schneider 2009). BibExcel also aids in preparing the input data for detailed network analysis.

Keyword statistics. Author and index keywords analysis was conducted and the result of the top 20 keywords is shown in Figure 4. As expected, we find that internet of things (IoT), supply chain management and food supply chain are the dominant keywords. We also note that traceability, sensor technology and packaging are common themes. This observation will be reinforced in our network analysis as well.

Affiliation statistics. BibExcel was used to extract the affiliation of authors. Then, corresponding to each affiliation, the country in which the institution is situated was taken out for further analysis. From Figure 5, it can be seen that institutions in China, United States, Netherlands and United Kingdom are the major contributors.

Network analysis of publications

Different software tools are available to conduct citations network analysis. Gephi was chosen for this study due to its visualization flexibility, advanced filtering capabilities, ability to work with different data formats, and several built-in network analysis toolboxes. In Gephi, published papers are shown as nodes

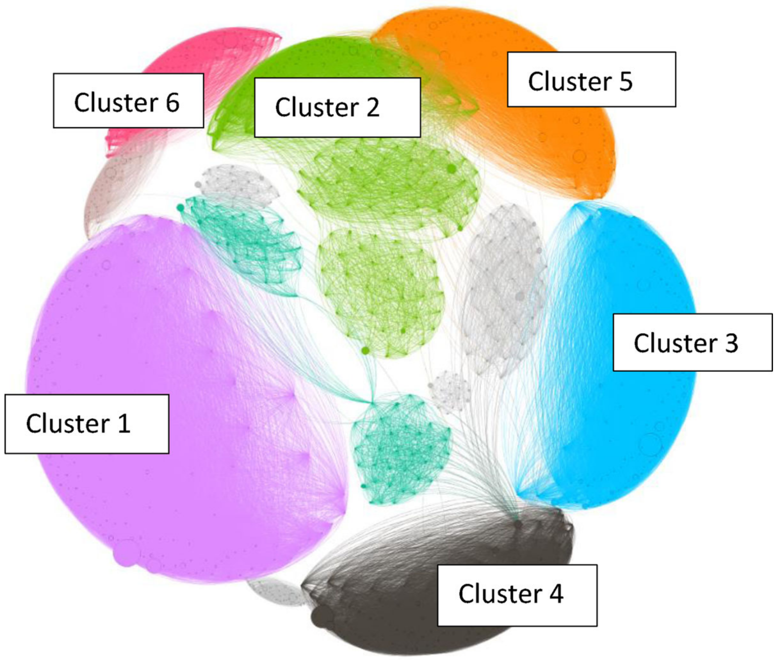

Figure 6. Structure of six main clusters.

and citations are represented by the arcs/edges between the nodes.

Co-citation analysis. Co-citation analysis is a technique to explore the relationships between authors, topics, journals, or keywords, thus explaining how these groups are related to each other (Small 1973; Pilkington and Liston-Heyes 1999). The co-citation map visualization is a form of exploratory data analysis (EDA) that relies on graph theory to explore the data structure (Pampel 2004). A co-citation map consists of a set of nodes representing journal articles and a set of edges representing the co-occurrence of nodes/articles in the reference list of papers of that map (Leydesdorff 2011). Publications are co-cited if they appear together in the reference lists of other documents. It has been shown that papers that are more often cited together by other papers are more likely to be related and hence belong to a similar subject area (Hjørland 2013). We use this concept to map and classify the literature of food supply chain management.

Using BibExcel and Gephi, we conducted a co-citation analysis of the reviewed papers to obtain insight into the different studied topics and their relationships. We have used modularity partition and PageRank for ranking (Mishra et al. 2016). It also allows for the manual adjustment of the repulsion strength, gravity, speed, node size and other characteristics (Bastian, Heymann, and Jacomy 2009). The Force Atlas layout of 911 nodes co-citation map is shown in Figure 6. The co-cited articles are connected while the poorly connected nodes shift away from the center.

Data clustering. The nodes of a network can be divided into clusters or modules where the density of edges is greater between the nodes of the same cluster compared to those of different clusters (Clauset, Newman, and Moore 2004; Leydesdorff 2011; Radicchi et al. 2004). A cluster is a group of well-connected articles in a research area with limited connection to papers in another cluster or research area. The resulted network graph is shown in Figure 6. We can see that there are six main clusters.

Given that papers that are more often co-cited are more likely to present similar subject areas (Hjørland 2013) and that papers within a cluster have strong co-citation relationship (Radicchi et al. 2004; Clauset, Newman, and Moore 2004; Leydesdorff 2011), careful analysis of papers of one cluster can define the area of the research focus of that cluster. Due to the high number of papers in each cluster, we completed this content analysis for the lead papers of each cluster. The lead papers of each cluster were identified based on their co-citation PageRank. The lead papers of each cluster are shown in Table 2. The six clusters contain 161, 153, 128, 116, 114, 78 documents, respectively. The major six clusters account for 75.79% of the co-cited papers. The contents and research areas of the leading papers were carefully examined to determine the research focus area of each of the six clusters. Then, co-citations cluster topics are summarized in Table 3. It was found that researchers belonging to Cluster 1 have examined the advanced packaging technologies for fresh food preservation such as modified atmosphere packaging (MAP)

Table 2. Co-citations cluster topics.

Cluster	Description	Top 5 papers
1	Active packaging, Modified Atmosphere Packaging (MAP) applications, Cold storage, packaging attributes, food waste, Low Ethylene Technology in Non-Optimal Storage Temperatures.	Zhang et al. (2008); Wu, Zhang, and Wang (2012); Zhang et al. (2015); Wrona, Bentayeb, and Nerín (2015); Wills (2015)
2	Food traceability technologies, agricultural products, Agri-food Supply Chain (AFSC) management, food quality and safety traceability systems, Information sharing.	Zhang and Bhatt (2014); Zou et al. (2014); Yang et al. (2014); Zhang, Zhao, and Qian (2017)
3	Food safety and quality, food safety legislation, food fraud and adulteration, network analysis.	Yapp and Fairman (2006); Zhang and Xue (2016); Zeng et al. (2017); Yaseen, Pu, and Sun (2018); Zhao, Mao, and Lu (2018)
4	RFID application in supply chains, microfluidics, optical sensor, WSN, monitoring system.	Wu et al. (2006); Liu, Zhou, and Mo (2012); Xuan, Gautam, and Suresh (2016); Ma and Du (2015); Xiao et al. (2016)
5	operations research (OR) in the service industry, Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, Industry 4.0, industrial information integration, Virtual objects, Hazard Analysis & Critical Control Points (HACCP).	Zhao, Xia, and Guan (2011a); Xing et al. (2013); Zeng (2015); Verdouw et al. (2016); Xu, Xu, and Li (2018)
6	Theoretical model, supply chain integration and operational performance, Quality Management (QM), organizational structure, internal integration and External integration.	Ward, Bickford, and Leong (1996); Zhao, Yeung, and Lee (2004); Zhao et al. (2011b); Wong, Boon-Itt, and Wong (2011); Zhang, Linderman, and Schroeder (2012)

Table 3. Food quality monitoring literature.

Food quality monitoring issues	References
Modeling and analysis of FSC network	Van der Vorst, Tromp, and Van der Zee (2005);
Modeling of product decay to improve FSC network design	Van der Vorst et al. (2007); Van der Vorst, Van Kooten, and Luning (2011)
Intelligent food transport system through shelf life modeling and use of IT	Xu (2011); Lin, Negenborn, and Lodewijks (2015); Bogataj, Bogataj, and Hudoklin (2017); Mejjaouli and Babiceanu (2018); Gružauskas, Baskutis, and Navickas (2018)
Quality and safety monitoring system based on internet of things	Ying and Fengquan (2013)
Using SCOR model (Supply-Chain Operations Reference-model) and IoT to improve quality and safety agricultural products.	Lianguang (2014)
Temperature management in food cold chains	Giannoglou et al. (2013); Wu and Zhao (2013); Aung and Chang (2014a); Zhang et al. (2016); Kim, Shin, and Lee (2016); Xiao et al. (2016); Xiao et al. (2017c); Ndraha et al. (2018)
Distribution planning and optimization of temperature setting for food storage in multi-item-multi-temperature vehicles	Hsiao, Chen, and Chin (2017)
Tracking temperature history to estimate quality loss of individual fruit in the cargo throughout a cold chain	Wu et al. (2018)
Supply chain food quality performance indicator in the Australian beef processing industry	Ding et al. (2014)
Different RFID technology, temperature and humidity sensor, WSN and ZigBee based quality traceability platforms used to effectively track and trace the supply processes of foods safety and quality	Gogou et al. (2015); Li et al. (2015); Liu et al. (2016); Tsang et al. (2018a); Witjaksono et al. (2018)
Tools to develop quality control and chain transparency	Wang et al. (2018)
Logistics and quality control activities analysis tool to reduce postharvest losses in fresh produce chains	Macheka et al. (2017)

applications, and active packaging. They also summarized the advantages and limitations of these technologies. In Cluster 2, key technologies for establishing traceability systems, such as coding and identification, real-time record keeping in the supply chain, intelligent decision making and early warning and data exchange and query, were summarized. Papers in this cluster have also used IoT to construct a technology framework of traceability systems. In addition, food traceability best practices were presented. The theme of the third cluster is to present the food safety approaches in terms of fraud type, implicated foods, adulterants, contaminants and abnormal conditions, and involved food sources, thereby outlining the implications for regulatory and enforcement strategies. Cluster 4 focuses on outlining applications of IoT in food and agricultural areas, their challenges and barriers to adoption. Cluster 5 reviews future research directions of operations research (OR) in the foodservice industry. Cluster 6 is mostly theoretical and conceptual. It focuses on quality management concepts; its strategies and practices. For example, Zhang, Linderman, and Schroeder (2012) have considered quality exploitation and quality exploration and provide insights on how quality management programs can be customized to improve firm performance.

We note that some future research directions were outlined in Clusters 4 and 5. More research is required to address the challenges that may come to the foreground during IoT adoption in FSC. They also call for the development of frameworks and models for the implementation and assessment of IoT adoption.

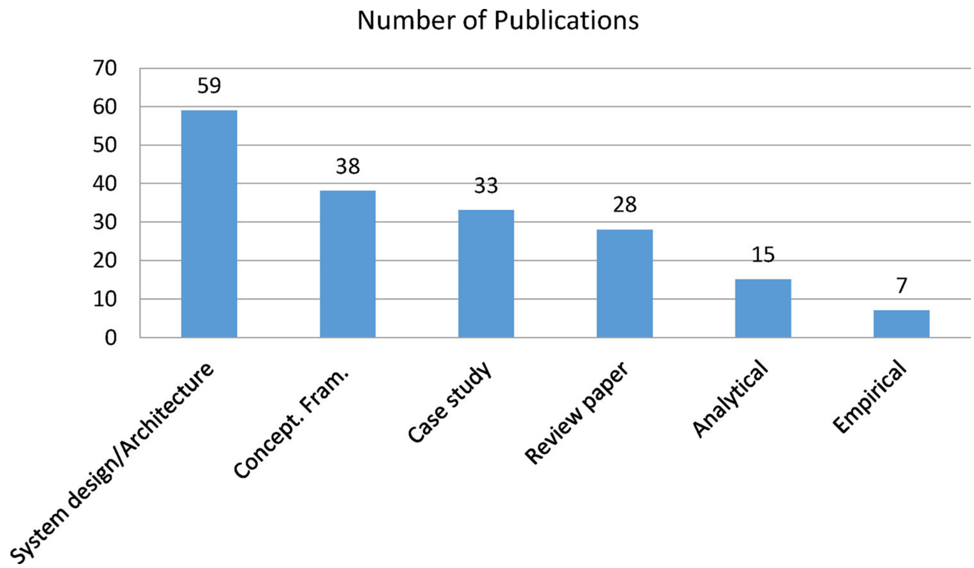

Figure 7. Distribution of papers by type of methodology.

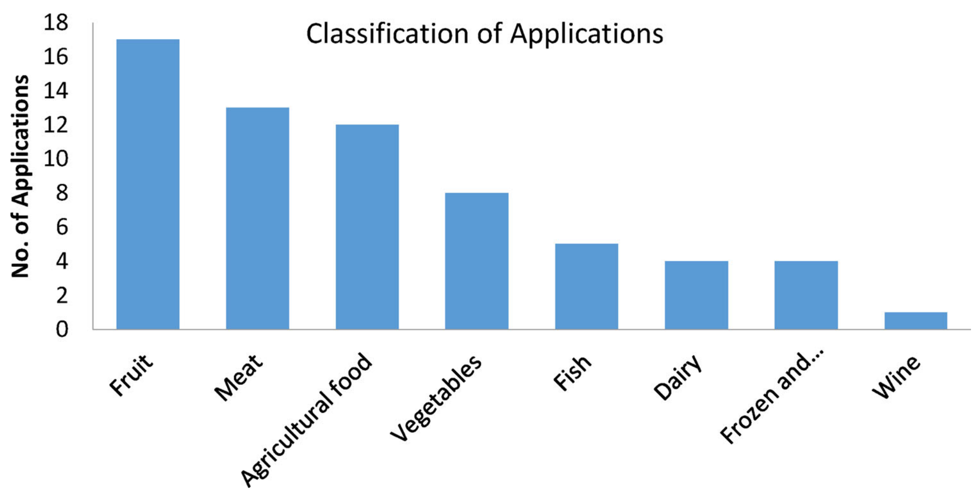

Figure 8. Distribution of papers by type of application.

Further categorization of papers

The reviewed papers were classified based on the type of contribution (review, conceptual framework or system design) as well as methodology (analytical, empirical or case study), as shown in Figure 7. System design is the most dominant while there are fewer analytical or empirical studies, which is understandable for a new field where most studies are focusing on design rather than operational models. Finally, we have also classified the different studies in their field of application in Figure 8. We find that fruit, agricultural food and meat are the top studied categories.

Main findings of the literature review

Food quality monitoring

As discussed earlier, the quality of food is dependent on how food products are handled at every touchpoint throughout the FSC. Proper management of the flow of FSC products requires a high level of visibility and effective traceability means. This can be achieved through real-time monitoring and tracking of food products location and conditions (e.g., temperature and humidity) throughout the supply chain. Table 3 summarizes the literature on food quality monitoring.

Traceability

In recent years, traceability aspects have become recognized as an essential tool for guaranteeing food safety and food quality. On the other hand, the design of a traceability system requires a thorough rethinking and reorganizing of the entire food supply chain. The reviewed literature has focused on the use of IoT

Table 4. Main traceability research trends and findings.

Traceability research issue	References
RFID technology use: Traceability in logistics and Traceability for anti-counterfeit operations	Aung and Chang (2014b); Cuiñas et al. (2014); Dabbene, Gay, and Tortia (2014); Chen (2015); Alfian, Syafrudin, and Rhee (2017a); Bai et al. (2017)
Implementation requirements: Consistency, data security and big data expertise	Giagnocavo et al. (2017)
Technology challenges: difficulty in handling the heterogeneous nature of the food supply chain	Badia-Melis et al. (2015b)
Traceability systems applications:	
• Wheat flour milling: RFIDs	• Qian et al. (2012)
• Cattle beef: RFIDs with PDA and barcodes	• Feng et al. (2013)
• Vegetables: "Gapless" traceability with RFIDs	• Mainetti et al. (2013b)
• Dairy (cheese): RFIDs	• Barge et al. (2014)
• Meat: IoT, EPCglobal	• Furdik et al. (2016); Chen (2017)
• Cold supply chain	• Óskarsdóttir and Oddsson (2019)
• General	• Bhatt et al. (2016); Olsen and Borit (2018)
Traceability for quality: grapes, seafood, honey peach	Wang et al. (2017); Xiao et al. (2017a); Wang et al. (2017); Wang et al. (2018)
Traceability for food safety and security	Zhang et al. (2013); Xiao et al. (2017b); Wang et al. (2017); Liu et al. (2018a)
Value of traceability to consumers	Jin, Zhang, and Xu (2017)

Table 5. Summary of smart packaging literature.

Smart packaging research issue	References
Different types of CO2 sensors	Puligundla, Jung, and Ko (2012)
Photochromic time temperature indicator (TTI) to monitor the time temperature history	Brizio and Prentice (2014); Tsironi et al. (2016); Zhang et al. (2016)
Smart time–temperature indicator	Brizio and Prentice (2015); Lorite et al. (2017)
Product tracking using IoT technology	Maksimović, Vujović, and Omanović-Miklić Anin (2015b); Tsang et al. (2018b)
intelligent packaging to reduce waste	Haass et al. (2015); Fang et al. (2017); Heising, Claassen, and Dekker (2017)
Computer systems that are used in the logistics and post-logistics phase of a food package's life cycle	Vanderroost et al. (2017)

Table 6. Blockchain-based traceability solutions.

Blockchain FSC research topics	References
Framework for intelligent blockchain-based supply chain quality management.	Chen et al. (2017b)
Agri-food supply chain traceability system based on blockchain and IoT technology	Tian (2016); Caro et al. (2018); Guo, Liu, and Zhang (2018); Lin et al. (2018)
FSC traceability system based on HACCP (Hazard Analysis and Critical Control Points), blockchain and Internet of things	Tian (2017)
Blockchain pilot implementation	Kamath (2018)
Blockchain and smart contracts implementation challenges	Galvez, Mejuto, and Simal-Gandara (2018); Tripoli and Schmidhuber (2018)
Pilot implementations	Kamath (2018)

technology for traceability and implementation and operational issues as shown in Table 4.

Smart packaging

The advancement in technology introduced different innovative and novel approaches in food packaging to achieve the consumers' demand for safe and high-quality foods. One such development is smart or intelligent food packaging technology. Adoption of suitable packaging technologies by the food industry can be useful to extend the shelf life, improve quality, safety, and provide information about the product. Packaging can be considered one of the most cost-effective and flexible ways to improve the cold chain of fresh produce (Biji et al. 2015; Defraeye et al. 2015; Yucel 2016). A summary of the issues related to smart packaging is included in Table 5.

Blockchain application in the food supply chain

Effective traceability systems are vital for minimizing the adverse effects of the production and distribution of unsafe or poor quality products. Consumers also demand verifiable evidence of traceability of provenance as an important criterion of food quality and safety. Recently, many papers are exploring blockchain-based solutions to develop effective traceability systems. As an example, blockchain is used for tracking the cause of bad quality in case of recalls. A summary of this line of research is provided in Table 6.

Table 7. Main IoT-based solutions and frameworks for the food supply chain.

IoT based solutions and frameworks	References
IoT systems applications:	
• Beef: Quality detection instrument using Mobile Electronic Nose.	Wijaya and Sarno (2015)
• Monitoring agricultural products quality and safety.	Liu et al. (2015); Barmpounakis et al. (2015); Yan et al. (2016); Liu et al. (2016); Balamurugan et al. (2016); Witjaksono et al. (2018); Wen et al. (2018)
• Mobile application for food freshness investigation.	Witjaksono et al. (2018)
• Restaurants food waste management.	Wen et al. (2018)
• IoT based cold supply chain monitoring.	Tsang et al. (2018a)
• IoT based cargo monitoring system for product quality.	Tsang et al. (2017)
• Iot and cloud computing based solution for cold supply chain monitoring.	Lu and Wang (2016)
• RFID and Critical Temperature Indicators sensors for real-time monitoring supply chain temperature.	Lorite et al. (2017)
• E-pedigree IoT based food traceability system	Alfian et al. (2017b)
• IoT based duck product traceability system.	Liu et al. (2018b)
• IoT based food adulteration monitoring system	Gupta and Rakesh (2018)
• An intelligent tracking system based on internet of things for the cold chain.	Luo et al. (2016)
• RFID monitoring for cold supply chains.	Ruiz-Garcia and Lunadei (2010)
• Optimization approach for increasing revenue of perishable product supply chain with the Internet of Things.	Yan (2017)
• IoT-based tracking and tracing platform for prepackaged food supply chain.	Li et al. (2017)
IoT frameworks:	
• Value-centric business-technology design framework.	Pang et al. (2015)
• IoT based logistic information systems architecture for agri-food supply chains	Verdouw et al. (2018)
• Conceptual model for IoT-enabled perishable food supply chain.	Zhang, Zhao, and Qian (2017)
• IoT based framework for food supply chain planning	Accorsi et al. (2017)
• Food supply chain virtualization	Verdouw, Beulens, and Van Der Vorst (2013); Verdouw et al. (2016)
• Three-level supply chain coordination of fresh agricultural products in the Internet of Things	Yan et al. (2017)
• A hierarchical data architecture for sustainable food supply chain management and planning	Accorsi et al. (2018)
• Green evaluation models based on IOT for agricultural products	Wang and Deng (2014)

Blockchain becomes relevant to our scope only when it is combined with IoT technologies. Blockchain finds many applications in the FSC, especially in the areas of traceability and provenance. Readers are referred to the many reviews that appeared recently (see for example: Duan et al. 2020; Mirabelli and Solina 2020; Zhang et al. 2019)

Proposed IoT solutions

IoT technologies, such as RFID and WSN, have started to be used in the food supply chain mainly for food quality monitoring, traceability and smart packaging (Xu 2011; Yan, Hu, and Shi 2012; Nukala et al. 2016; Liu 2015; Maksimović, Vujović, and Omanović-Miklić Anin 2015a; Maksimović, Vujović, and Omanović-Miklić Anin 2015b; Furdik et al. 2016;).

However, the adoption of IoT in the food supply chain is still in its nascent phase. Many challenges are facing the implementation of IoT on a large scale. The main challenges include the cost of IoT technology and the development of specific and well-adapted sensors to the food environment (Ping et al. 2018). Another challenge is dealing with the huge volume of data generated by this technology that need powerful software and hardware as well as a secure environment. In addition, the lack of standardization in IoT systems and platforms is making it difficult for companies to make significant investments in technology. Lack of standardization is also leading to a case-by-case implementation approach due to the high diversity of products (Badia-Melis et al. 2018). Finally, other complicating factors are stemming from the lack of government regulations and poor internet infrastructure (Kamble et al. 2019).

Table 7 summarizes some recent IoT-based solutions and frameworks for the food supply chain.

Discussion and future research directions

Studying FSC quality is a challenging task. The FSC includes different aspects of food industries from manufacturing (farming and food production), logistics (packaging and distribution), to services (retail and catering). The FSC has a complex structure since food can be a commodity, an ingredient and a meal. The value and quality of food can change depending on its nature and stage at the supply chain. It is difficult to estimate the FSC's size and impact. While the World Bank estimates that the food industry constitutes 10% of the global gross domestic product, which would put it at about US$8.7 trillion in 2019, Euromonitor's estimate for food packaged goods and foodservice stands at about US$3.45 trillion.

The FSC also has interesting, but sad contrasts: The Food and Agriculture Organization (FAO) of the United Nations estimates that one-third of the food produced in the world for human consumption is lost—approximately 1.3 billion tons or the equivalent of about US$1 trillion. At the same time, FAO estimates that about 815 million people, or 10.7% of the world population, were suffering from chronic undernourishment in 2016. This points to a systematic imbalance of supply and demand in the FSC. With the advances in technology, such as blockchain and IoT, there is a growing hope that this gap between supply and demand will be reduced. We believe, and hope, that the field of operations management can play an important role in aiding emerging innovative IoT technologies to address the anomalies between food waste and hunger.

Despite the importance of FSC and its operational challenges, there is still a scarcity of literature on quality in FSC in the area of quality and operation management related journals. The purpose of our review is to introduce more operations and production management researchers to this challenging and important area of research. To this end, we propose the following future research directions based on the literature review and our knowledge of food supply chain management.

Some retailers, or food distributors, mix produce that is coming from different sources or a single source but in different batches, and sell it as one lot. The decision of mixing is usually done in an ad-hoc way. With the availability of tracking and identification data, there is an opportunity to make a more informed decision by looking at the state of quality, level of inventory, demand, and pricing to investigate the *effect of product mixing*.

The continuous flow of IoT sensor data form big data sets. The resulting supply chain quality optimization problems get larger as well. Leading solvers, such as CPLEX, often cannot even read the problem input data before they run out of memory. In such circumstances, it is not possible to obtain an exact solution in a reasonable time, especially when decisions are needed on a real-time basis. There is a need for research to develop *computationally efficient heuristics* for such problems as well as for designing computational processes that can handle large data sets for input and pre-processing to optimization solvers.

There is an increasing trend in warehouse farming, where plants and vegetables are grown while being stored and/or transported. To improve food quality in such supply chains, it is important to understand the process of growth and its interactions with the dynamics of picking and moving the item, i.e., to have an *integrated production and logistics approach*. This growing field is sometimes referred to as *precision agriculture* defined by the National Research Council (1997) as "a management strategy that uses information technology to bring data from multiple sources to bear on decisions associated with crop production." The use of intelligent infrastructure, such as IoT, allows for the control of agricultural products quality from inception, to production and distribution.

IoT data can improve food quality and track across the supply chain but at a cost of investing in IoT sensors and technology. The impact of this investment on food quality improvement may depend on whether it is invested upstream or downstream in the supply chain. Investment in IoT would necessitate some coordination between the supply chain entities. It is therefore an interesting research question to investigate how to *coordinate investment in IoT to improve food quality* in a supply chain. This research is currently being investigated by the authors of this paper.

Given the early stage in which IoT sensors are being deployed, there is still some uncertainty in the quality of measurements and data transmission. This uncertainty can reduce the benefits introduced by IoT and it is important to assess the *impact of data quality* and possible remedies.

Given the availability of IoT data from different food quality sensors, such as temperature, humidity and air quality, it is expected that more comprehensive quality estimation functions can be developed which incorporate these quality inputs. There is a need for the *development of new quality model functions* that can be used to enrich demand and inventory management models.

Unlike electronics and consumer packaged goods that keep their form while in use by the consumers, food products often get depleted the moment they are consumed. This has put food products research at a disadvantage due to limited ability to make use of the wave of tools for collecting after-sales data. For instance, the use of smartphones nowadays relies heavily on sensors such as in location-based apps. On the other hand, a banana is typically bought and consumed the same day. Understanding the consumption process, in the context of intelligent refrigerators and smart homes, can improve the last-mile delivery operations for the food supply chain. *Involving customers in the data collection process* can also provide feedback information to improve upstream processes and improve downstream customer satisfaction.

With the advent of IoT technology at the farming level through precision agriculture, we can now more accurately trace the origin of food products. The ability for *quality monitoring in the presence of precision agriculture is leading to supply chain disintermediation.* This has also opened the doors to reconfiguring the farmer-consumer supply chain. There is a need for research on how quality can be monitored and controlled in the absence of traditional supply chain intermediaries.

With the advances in IoT technology and the abundance of data, there is an interest in studying *food* quality management in the context of Industry 4.0 and how will IoT impact the practice of food quality management? This has also brought in an opportunity to develop new models for food quality management. For example, how can IoT big data be used in designing new machine learning-based pan-supply chain quality measurement tools?

An overarching feature of this literature review is that there are many developments in IoT technology that relate to FSC, but there is a need for further development of management systems that incorporate these developments to better support food quality and safety in FSC.

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