International Journal of Production Research

ISSN: 0020-7543 (Print) 1366-588X (Online) Journal homepage: https://www.tandfonline.com/loi/tprs20

# Internet of things and supply chain management: a literature review

Mohamed Ben-Daya, Elkafi Hassini & Zied Bahroun

**To cite this article:** Mohamed Ben-Daya, Elkafi Hassini & Zied Bahroun (2017): Internet of things and supply chain management: a literature review, International Journal of Production Research, DOI: 10.1080/00207543.2017.1402140

**To link to this article:** https://doi.org/10.1080/00207543.2017.1402140

*International Journal of Production Research*, 2017
https://doi.org/10.1080/00207543.2017.1402140

# Internet of things and supply chain management: a literature review

Mohamed Ben-Daya[a]*, Elkafi Hassini[b] and Zied Bahroun[a]

[a]*Industrial Engineering Department, American University of Sharjah, Sharjah, United Arab Emirates;* [b]*DeGroote School of Business, McMaster University, Hamilton, Canada*

(*Received 6 August 2017; accepted 31 October 2017*)

This paper explores the role of Internet of Things (IoT) and its impact on supply chain management (SCM) through an extensive literature review. Important aspects of IoT in SCM are covered including IoT definition, main IoT technology enablers and various SCM processes and applications. We offer several categorisation of the extant literature, such as based on methodology, industry sector and focus on a classification based on major supply chain processes. In addition, a bibliometric analysis of the literature is also presented. We find that most studies have focused on conceptualising the impact of IoT with limited analytical models and empirical studies. In addition, most studies have focused on the delivery supply chain process and the food and manufacturing supply chains. Areas of future SCM research that can support IoT implementation are also identified.

**Keywords:** Internet of Things (IoT); supply chain management; industry 4.0; supply chain processes; smart supply chain

## 1. Introduction

In modern business management, 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). As such, supply chains are operating under an ever-changing environment and are vulnerable to a myriad of risks at all levels. This environment is an ever-changing landscape because of many factors. Many supply chains extend over wide geographical areas and are vulnerable to many global risks (Butner 2010). Customers are more and more demanding in terms of product customisation, price and level of service (Christopher 2016). Products complexity is also increasing due to the high clock speed in many industries following the rapid changes in technology and the continuous introduction of new products to the market (Simchi-Levi, Kaminsky, and Levi 2003). Furthermore, the external environment is highly dynamic due to economic (energy cost, prices and availability of raw materials, currency exchange rates), social (unrest, demanding customers) and natural factors (extreme weather conditions, earthquakes, tsunamis).

In order to survive in such a complex environment, companies need to be extremely agile and build a high level of resilience and risk mitigation capabilities and structural flexibility that allow rapid response to these challenges. Christopher and Holweg (2011) define structural flexibility as the ability of the supply chain to adapt to fundamental changes in the business environment. However, flexibility and resilience come at an additional cost in the form of additional resources such as buffer inventory and extra capacity, and higher coordination cost (Christopher and Holweg 2011). In order to balance the required level of resilience and flexibility and the cost of achieving it, firms need to have high visibility of the whole supply chain, the necessary velocity to respond quickly to changes and effective collaboration with suppliers and customers. Christopher (2016) summarised the principles that can guide supply chain managers into what he calls the '4Rs': responsiveness, reliability, resilience and relationships.

Information technology (IT) has been, and continue to be, an essential enabler for effective supply chain management (SCM) (Ross 2016). It plays a critical role in helping supply chains deal with the challenges of ever-changing environment and a myriad of risks at all levels. IT has made a major impact on the nature and structure of supply chains due to its ability of 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), one of the latest IT developments, 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. These new

*Corresponding author. Email: mbendaya@aus.edu

capabilities offer tremendous opportunities to deal more effectively with SCM challenges. 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, analysed 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. What was lacking so far is not the availability of information but rather the technologies for collecting and processing big data and the lag between data collection and action. IoT will allow the reduction in the time between data capture and decision-making that enables supply chains to react to changes in real time allowing levels of agility and responsiveness never experienced before (Ellis, Morris, and Santagate 2015). IoT will also enable remote management of supply chain operations, better coordination with partners and can provide more accurate information for more effective decision-making.

This paper deals with IoT and its impact on supply chain management (SCM) through an extensive literature review. This review covered important aspects of IoT in SCM including IoT definition, main IoT technology elements needed in its implementation in a supply chain context, and various SCM applications. The extant literature is categorised according to several classification schemes, including methodology, industry sector and focus and major supply chain processes. A bibliometric analysis of the reviewed literature is presented as well. The current review reveals that the research dealing with analytical models and empirical studies is very limited. Most studies have focused on conceptualising the impact of IoT. In addition, most studies have focused on the delivery process, the food and manufacturing supply chains. Following the review, we identified areas of future SCM research that can support IoT implementation.

This paper is organised as follows. Section 2 provides background information about IoT including historical background, definitions and enabling technologies and platforms. We explain our review methodology in Section 3 where we also provide summary bibliometric analysis. An extensive and representative literature review is presented in Section 4. The focus is on IoT application in various SCM processes. Section 5 contains a discussion of the reviewed literature. Finally, opportunities for future research directions and conclusions are included in Section 6.

## 2. About IoT

In this section, we provide a discussion on the history of IoT and its enabling technologies. We also offer a definition of IoT that is relevant to supply chain management.

### 2.1 *Historical background*

The precursor to IoT is the concept of connected devices that started in the early 1990s at the Auto-ID Centre at MIT. Reportedly, Kevin Ashton, director of the Centre, has coined the term IoT in 1999 (Greengard 2015). In 1997, Ashton considered the possibility of using radio-frequency identification (RFID) tags to track products through Procter and Gamble's supply chain. RFID tags were used to read and identify objects and then transmit the information wirelessly through a network. Prior to that, industry adoption of RFID tags started in 1980 (Xu, He, and Li 2014). Then a new concept of sensors and actuators through a wireless sensor network (WSN) appeared to sense, track and monitor objects with applications in healthcare and traffic management (Xu, He, and Li 2014). Nowadays, these networks are enriched with GPS devices, smartphones, social networks, cloud computing and data analytics to support the modern concept of IoT.

In Europe, and particularly Germany, IoT is one of the founding technologies of Industry 4.0 in the manufacturing sector. Industry 4.0 refers to the fourth industrial revolution where the three first industrial revolutions are related to mechanical power (Industry 1.0), mass production (Industry 2.0) and digital revolution (Industry 3.0). Zhou, Liu, and Zhou (2015) define the concept of industry 4.0 as the integration of information and communications technologies with industrial technology.

In addition to IoT technology, Industry 4.0 needs cyber–physical systems (CPS) and cloud manufacturing (CM). A CPS is composed of machines, storage systems and production facilities that could autonomously exchange information, trigger actions and monitor each other (Kagermann, Wahlster, and Helbig 2013). According to Cheng et al. (2016), a CPS links a manufacturing entity virtual (computing) and physical (machines) elements by integrating analogue/digital hardware. IoT provides the needed platform to connect the CPS using a network of sensors, actuators and devices. IoT platforms use generally cloud-computing capabilities in external data centres, which led to the concept of cloud manufacturing (CM) in the industry 4.0 context.

### 2.2 *Defining IoT*

Many definitions of the IoT are available in the literature. According to Atzori, Iera, and Morabito (2010), the main reason for this is that IoT is composed of two words: 'Internet' and 'Things' and so we have two main visions. The first vision is mainly oriented towards the 'Internet' or the network component and the second one is oriented towards the 'things' component. The first definitions of IoT are more 'things' oriented (Atzori, Iera, and Morabito 2010) and concern mainly the RFID tags that are connected to a network to transmit identification information (Xu, He, and Li 2014). Later, more 'things' appeared as sensors and actuators to englobe today's mobile devices in general. Below we include a representative selection of definitions to reflect the variety in IoT interpretation:

> Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts. (INFSO 2008)

> The term "Internet-of-Things" is used as an umbrella keyword for covering various aspects related to the extension of the Internet and the Web into the physical realm, by means of the widespread deployment of spatially distributed devices with embedded identification, sensing and/or actuation capabilities. Internet-of-Things envisions a future in which digital and physical entities can be linked, by means of appropriate information and communication technologies, to enable a whole new class of applications and services. (Miorandi et al. 2012)

> Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless large-scale sensing, data analytics and information representation using cutting edge ubiquitous sensing and cloud computing. Gubbi et al. (2013)

> A loosely coupled, decentralized system of cooperating Smart Objects (SOs). An SO is an autonomous, physical digital object augmented with sensing/actuating, processing, storing, and networking capabilities. SOs are able to sense/actuate, store, and interpret information created within themselves and around the neighboring external world where they are situated, act on their own, cooperate with each other, and exchange information with other kinds of electronic devices and human users. Fortino and Trunfio (2014)

> Dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network. Xu, He, and Li (2014)

> Group of infrastructures interconnecting connected objects and allowing their management, data mining and the access to the data they generate. (Connected objects are define as Sensor(s) and/or actuator(s) carrying out a specific function and that are able to communicate with other equipment. It is part of an infrastructure allowing the transport, storage, processing and access to the generated data by users or other systems. Dorsemaine et al. (2015)

Our goal here is to offer a definition of IoT as it relates to supply chain management. A supply chain is a set of entities and processes that are involved in fulfilling a customer order. The entities often include suppliers, factories, distributors, retailers and customers. According to the SCOR model (APICS 2015) supply chain processes are classified as plan, source, make, deliver, return and enable. As defined in Hassini (2008), the role of supply chain management is to 'maximise the surplus: the price paid by the end customer minus all the costs incurred throughout the supply chain'.

Given our focus in this paper on IoT and supply chain management, we offer this definition for IoT:

> The Internet of Things is a network of physical objects that are digitally connected to sense, monitor and interact within a company and between the company and its supply chain enabling agility, visibility, tracking and information sharing to facilitate timely planning, control and coordination of the supply chain processes.

Our proposed definition includes four key features: (i) The requirement for digital connectivity of the physical things in the supply chain; (ii) The nature of this connectivity is proactive allowing for data storage, analysis and sharing; (iii) The communication involves processes within an organisation as well as interorganisation transactions covering all major supply chain processes; and (iv) IoT will facilitate planning, control and coordination of the supply chain processes.

A closely related concept to IoT is Industry 4.0 or Industrial IoT (IIoT). As mentioned earlier, Industry 4.0 is the product of combining CPS and IoT to the industrial automation domain (e.g. see Wollschlaeger, Sauter, and Jasperneite 2017). Thus, IoT is credited for being an enabler of Industry 4.0 that led to a fourth industrial revolution. The 'things' in Industry 4.0 could include smart products, smart machines and smart services such as quality-controlled logistics and maintenance.

### 2.3 *IoT technology*

As in Xu, He, and Li (2014), a typical IoT network includes four main essential layers:

(1) A *sensing layer* that integrates different types of 'things' like RFID tags, sensors, actuators;
(2) A *networking layer* that supports information transfer through wired or wireless network;
(3) A *service layer* that integrates services and applications through a middleware technology; and
(4) An *interface layer* to display information to the user and that allows interaction with the system.

In Table 1, we provide some communication and data IoT protocols (Postcapes 2017). Recent protocols are specifically designed for IoT devices such as NB-IoT, LoraWan or Sigfox. They all use low-power wide-area networks (LPWAN) in order to connect at a low bit rate a large number of devices with low energy consumption and low cost. Indeed, remote smart machines or embedded sensors usually only need to send small quantity of data at regular intervals and sometimes they need to connect in remote areas without the traditional wireless or cellular infrastructure and without a convenient power supply (Postcapes 2017).

Lee and Lee (2015) defined five key IoT technologies:

(1) Radio-frequency identification (RFID): It allows identifying, tracking and transmitting information. There are five main classes of RFID tags (López et al. 2011). The class 1 tags are only passive tags with a read/write memory. Some security related functionalities are added to class 2 tags. Semi-passive tags (class 3) are powered by a battery and may include sensors. Active tags (class 4) are also battery-powered and can communicate with similar tags. Finally, class 5 tags can activate other tags and are directly connected to back-end networks.
(2) Wireless sensor networks (WSN): It is a network composed of a set of sensors to monitor and track the status of different devices like their location, movements or temperature. Sensors can be used for a multitude of purposes such as temperature, pressure, flow, level, imaging, noise, air pollution, proximity and displacement, infrared, moisture and humidity and speed (Rayes and Salam 2016). They also can cooperate and communicate with RFID tags (Lee and Lee 2015).

Table 1. Some IoT protocols (Postcapes 2017).

| Type | Protocol | Features |
|---|---|---|
| Infrastructure | IPV6 | Internet layer protocol for transmission across IP networks |
| | 6LoWPAN | Low-power wireless personal area networks. Adaption of IPV6 |
| Communication/transport | IEEE 802.15.4 | Physical layer and media access control used as a basic standard for other communication protocols such as Zigbee |
| | Bluetooth | Transfer data up to 3 Mbps and a maximum range of 100 m |
| | Zigbee | Can handle a maximum number of 1024 nodes with a maximum range of 300 m and based on IEEE 802.15.4 standards |
| | Wifi | Wireless local area networking based on the IEEE 802.11 standards. An access point has usually a range of 20-m indoors a greater range outdoors |
| | WiMax | Wireless metropolitan area networks based on IEEE 802.16 standards. The range for fixed stations can reach 50 km and for mobile stations between 5 and 15 km |
| Communication/transport: low-power wide-area networks (LPWAN) | NB-IoT | Narrow Band IoT is a radio technology standard specifically designed for indoor coverage of a large number of devices with low cost, long battery life and using cellular telecommunications bands |
| | LoraWan | Wireless Network protocol for battery-operated devices in regional or global network |
| | Sigfox | Global wireless network for securely connecting devices to the cloud with a low energy consumption and low cost |
| Data protocols | MQTT | Message Queuing Telemetry Transport to enable publishing messaging model in a lightweight way for a machine-to-machine connectivity |
| | MQTT-SN | Specifically designed for sensor networks |
| | XMPP | Open source technology for Extensible Messaging and Presence Protocol mainly used for real-time communication and people to people communication |
| | XMPP IoT | Specifically designed for machine-to-machine and machine-to-people communication |

Table 2. Representative list of IoT Platforms (M&S Consulting 2017).

| IoT platform | Connectivity (more than internet) | Security | Event monitoring | Machine learning |
|---|---|---|---|---|
| Amazon Web Services (AWS) | x | x | x | x |
| Carriots | x | x | x | |
| Cisco IoT Cloud Connect | x | x | x | |
| GE Predix | x | x | x | x |
| IBM Watson | x | x | x | x |
| Microsoft Azure | x | x | x | x |
| Kaa | x | x | x | x |
| Oracle IoT | x | x | x | x |
| Salesforce IoT platform | x | x | x | |
| SAP Leonardo | x | x | x | x |
| Thingworx | x | x | x | x |

(3) Middleware: It is a service-oriented software layer that allows software developers the possibility to communicate with heterogeneous devices like sensors, actuators or RFID tags.
(4) Cloud computing: It is an internet-based computing platform where a pool of different computing resources (computers, networks, storage, software, etc.) can be shared and accessed on demand. Cloud computing is critical to IoT deployment because of the huge volume of data generated by IoT devices and the need for it to be analysed with high-speed processing computers to enable real-time and efficient decision-making (Lee and Lee 2015). Many IoT cloud platforms are available on the market. They play the same role as the middleware software and their main purpose is to connect IoT devices and IoT applications. They help transmit and secure data from IoT devices to ERP systems and business intelligence software to provide decision-makers with real-time information. Table 2 includes the most common IoT platforms and their key characteristics. In this table, we classified the features into four categories: connectivity, security, event monitoring and advanced analytics, as per the platform's machine learning capabilities. Cloud-computing services represent an efficient alternative to own and manage data centres (Bonomi et al. 2014). However, for some latency-sensitive applications, companies may need local and on premise storage, computing and communication capabilities (Bonomi et al. 2014). The concept of fog computing mixes local and cloud-computing services and consists in 'a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional cloud computing data centres' (Bonomi et al. 2012). Indeed, IoT deployment requires mobility support, geo-distribution, location awareness and low latency that can only be achieved through fog computing capabilities (Bonomi et al. 2012).
(5) IoT applications: they enable device to device and humans to device interactions. IoT applications constitute the interface between the user and the devices. They should be able to present data in an intuitive way, identify problems and suggest solutions (Lee and Lee 2015).

## 3. Review methodology and summary

In this section, we describe how we conducted our literature search as well as the procedure we used to select the reviewed literature. We also categorise the studied literature and present several summary statistics. Finally, inspired by Fahimnia, Sarkis, and Davarzani (2015) and Mishra et al. (2016), we include the results of a bibliometric and network analysis of the reviewed papers.

### 3.1 *Review methodology*

The main objective of a literature review is to map and evaluate the relevant and existing literature to identify future research questions (Tranfield, Denyer, and Smart 2003). Our literature review method has two stages: a systematic literature review followed by a bibliometric analysis. This approach has been called 'Systematic Literature Network Analysis (SLNA)' by Colicchia and Strozzi (2012). The method has been found to be more objective and suitable for studying emerging fields and their trends (e.g. see Fahimnia, Sarkis, and Davarzani 2015; Mishra et al. 2016; Strozzi et al. 2017). To map the existing literature, we started by defining the best key words for collecting the most relevant literature to our topic. We have chosen a combination of 'Internet of Things', 'supply chain', 'supply chain management', 'Industry 4.0', 'smart supply chains'. We mainly used Google Scholar (www.scholar.google.com) to look for different types of papers. The application of IoT concepts in supply chains is still recent and for that reason, we used Google Scholar rather than Web of Science or Scopus to search the relevant literature because it is a wider database. We also searched directly on some publishers' websites such as Elsevier (www.sciencedirect.com), Springer (www.springerlink.com), Taylor & Francis (www.tandf.co.uk) and Emerald (www.emeraldinsight.com). We then refined our search and studied carefully each paper to only select the most relevant papers to our topic. Indeed, there are many studies that have looked, for example, at the impact of RFID on supply chain operations. In this review, we focused only on the studies that have explicitly addressed IoT implications on the supply chain, for example, when the RFID tag has the capability to communicate wirelessly with other 'things' in the supply chain. For this reason, we only considered papers that were published post-2008 and for RFID papers that were published pre-2008, the reader can refer to the reviews by Sarac, Absi, and Dauzère-Pérès (2010) and Lim, Bahr, and Leung (2013).

We repeated this cycle of searching, studying and selecting relevant papers many times from January 2017 to June 2017 given that the topic is still new and very dynamic. During each iteration, we enriched our literature review by new papers. We finally selected 166 studies. Table 3 details the selected studies by type of publication. We note that about 20% of the reviewed literature appeared in conference proceedings and books.

### 3.2 *Bibliometric analysis*

We conducted a bibliometric analysis using BibExcel software (Persson, Danell, and Schneider 2009). We have chosen this software for its flexibility and compatibility with network analysis tools such as Gephi software (Mishra et al. (2016). The initial research information system (RIS) citations file data were obtained from Scopus and Google Scholar. We then obtained some relevant statistics using BibExcel.

Figure 1(a) shows the publications distribution from 2008 to 2017. It is clear that there is a sharp increase in the number of publications since 2015 (2017 publications include only publications up to June 2017) indicating an increased interest in the subject.

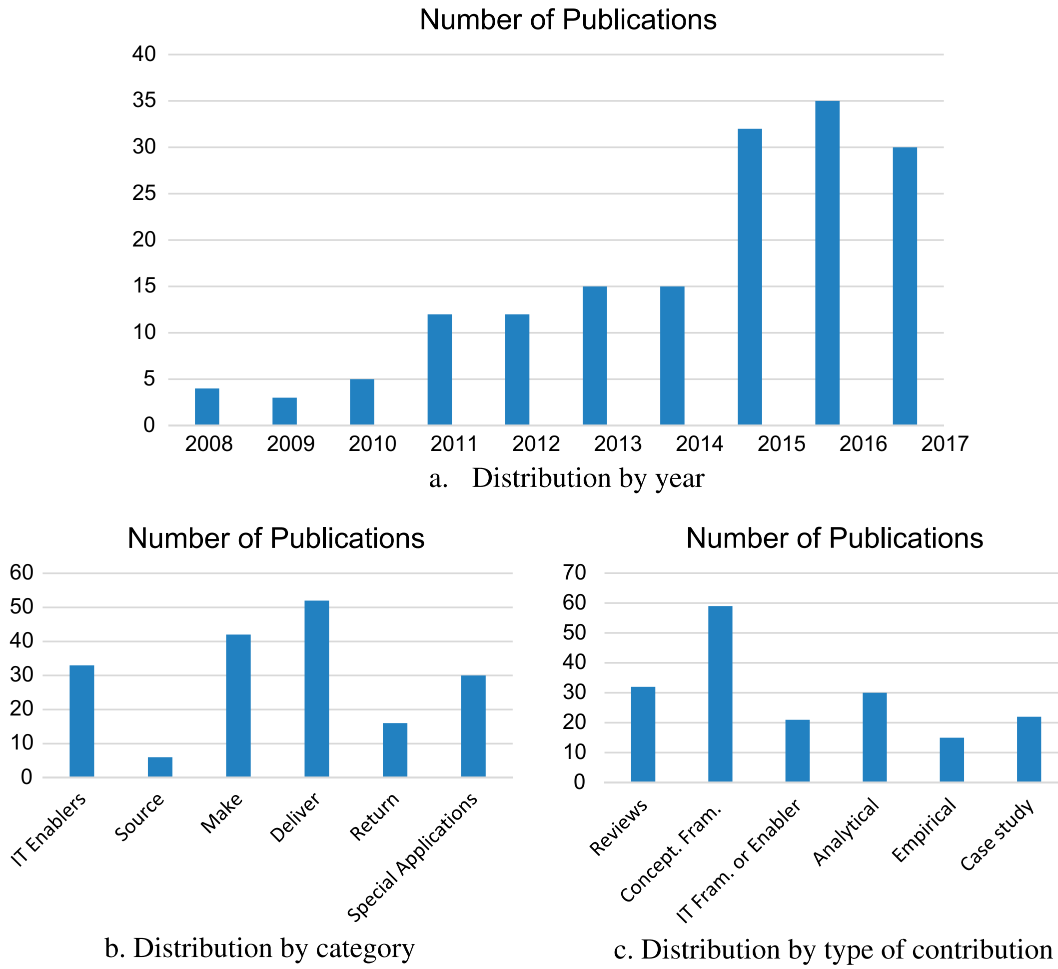
Table 3 shows the top contributing journals. We included only those journals that had at least five or more papers. We note that close to 21% of the studies appeared in the International Journal of Production Economics (13.2%) and the International Journal of Production Research (7.2%). This may be an indication of the openness of these two journals to publications in the area of new disruptive and innovative technologies. It may also be because these two journals are highly ranked according to their recent impact factors as well as their ABDC rankings.

We then classified the papers according to six categories: two based on applications (IT enablers and special applications) and the remaining four based on the main SCOR model processes (Source, Make, Deliver, Return and Enable) (APICS 2015). We note that a paper can belong to more than one category. Figure 1(b) shows that most of the papers are related to the 'make' or 'deliver' processes. Few researchers were interested in applying IoT concepts in the 'Source' or 'Return' processes. This can be explained by the fact that by design IoT technologies are more amenable to the manufacturing and transportation operations in the supply chain. However, we expect there will be more interest in the sourcing and return functions given the increase of supplier disruptions and online shopping.

We also classified the reviewed literature according to the type of contribution (review, conceptual framework or IT enabler) as well as methodology (analytical, empirical or case study). We note that one paper can belong to more than

Table 3. Statistics for the reviewed literature.

| *Type of publication* | Frequency |
|---|---|
| Journal | 132 |
| Conference | 22 |
| Book series | 6 |
| Book Chapter | 4 |
| Book | 2 |
| *Journal* | Number |
| International Journal of Production Economics | 22 |
| International Journal of Production Research | 12 |
| Others | 132 |



a. Distribution by year

b. Distribution by category

c. Distribution by type of contribution

Figure 1. Bibliometric analysis results.

one type. We can see in Figure 1(c), that most of the authors developed conceptual frameworks or detailed IT enablers for implementing IoT related concepts in supply chain management. There are less analytical or empirical studies which is understandable for a new field. However, we note that their number is increasing in 2016 and 2017.

Using BibExcel and Gephi, we conducted co-citation analysis on the reviewed papers to obtain insight on the different studies topics and their relationships. We have used modularity partition and PageRank for ranking (Mishra et al. 2016). The resulted network graph is shown in Figure 2. We can see that there are three main clusters. Cluster 1, 2 and 3 accounted for about 58, 19 and 15% of the co-cited papers, respectively. The top five papers, according to PageRank ranking, related to these clusters are summarised in Table 4.

Cluster 1 is formed by early studies that looked at the use of RFID tags in supply chains with a focus on inventory accuracy. Cluster 2 contains studies that proposed IoT technology frameworks as well as reviewed the literature related to IoT technologies. Finally, Cluster 3 groups studies that addressed supply chain sustainability performance measures and how the adoption of innovative technologies can help in that field. From Figure 2, we note that the papers in Cluster 2 are independent. Furthermore, the clusters are not connected to each other. One possible interpretation is that this field is still in its infancy and most studies are early independent attempts at understanding the impact of IoT on the supply chain. This justifies the need for our review to synthesise the different studies and offer possible future research directions.

## 4. Literature review

In this section, we report on our literature review. We start by positioning our review with respect to other recent reviews in this area. We then classify the literature into six categories based on the type of applications and the studied supply chain process.

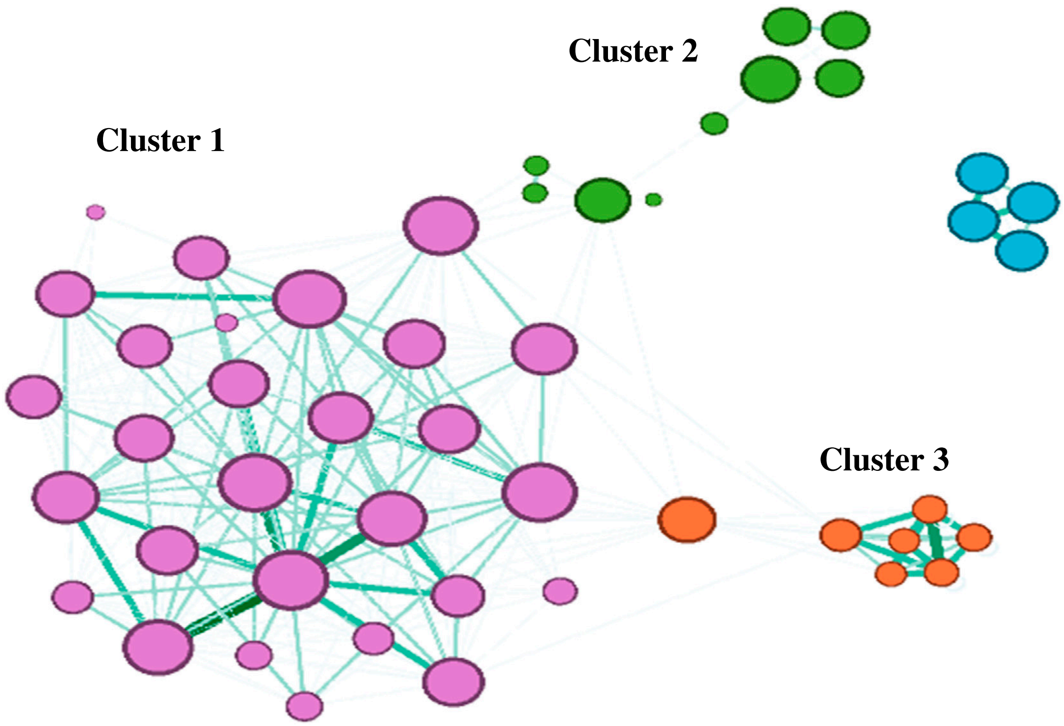



Figure 2. Co-citation clusters graph.

Table 4. Co-citations cluster topics.

| Cluster | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|
| Papers | Heese (2007), Angeles (2005),Sarac, Absi, and Dauzère-Pérès (2010), Gaukler, Seifert, and Hausman (2007), Tajima (2007) | Karakostas (2013), Meyer, Främling, and Holmström (2009), Li et al. (2012), Atzori, Iera, and Morabito (2010), Lim, Bahr, and Leung (2013) | Barratt and Oke (2007), Srivastava (2007), Vachon and Mao (2008), Vachon and Klassen (2008), Zhu and Sarkis (2004) |
| Topics | Inventory accuracy, RFID application in supply chains | Technology frameworks and reviews | Performance measurement, Sustainability |

### 4.1 *Related literature reviews*

There are several literature reviews on the subject of IoT and supply chain. In this section, we summarise those that are most relevant to our review and explain how our review is different. Musa and Dabo (2016) focus on RFID uses in supply chain management in the period 2000–2015. Strozzi et al. (2017) review the literature on smart factories and thus focus only on the manufacturing sector. In addition, the authors restrict their review to only those papers that are listed on Web of Science between 2007 and 2016. Liao et al. (2017) have focused on Industry 4.0, with no particular attention to supply chain management or the wider applications of IoT that extend beyond Industry 4.0, as we have explained in Section 2. Liu et al. (2017) conducted a citation and content analysis of IoT literature with a focus on technology. Naskar, Basu, and Sen (2017) study applications of RFID in the supply chain. They have classified the literature based on the type of studies and supply chain processes. We find that these recent reviews either focus on a subset of IoT technologies or address a particular application area. Our review takes a more comprehensive look at IoT technologies with a focus on impacts on supply chain management in different sectors and application areas.

### 4.2 *IoT Applications in SCM processes*

One framework for understanding supply chains is the process centric view of the supply chain (Chopra and Meindl 2013). The SCOR model is a well know such framework that divides the supply chain processes into Plan, Source, Make, Deliver, Return and Enable (APICS 2015). This model has been widely accepted in practice largely because of its ability to link processes to performance metrics and as such has been employed to conduct process centric views of supply chain-related literature reviews (e.g. see Naskar, Basu, and Sen 2017). IoT brings several capabilities to aid supply chain management, such as cost-saving, inventory accuracy and product tracking. However, the extent of IoT impact on the different supply chain processes is not known. It is thus our goal in this review to identify the role of IoT on supply chain management through a systematic analysis of the literature based on which supply chain process is being impacted. Since the Plan process is implicated in all other SCOR processes, it our literature analysis we focus on the other SCOR processes. We start with the Enable process to explain the different IoT technology that will be relevant for application in the other processes.

#### 4.2.1 *IT Enablers*

Most of the authors generally agree that the enabling technologies for the IoT are usually composed of four main layers: (i) a data collection layer using mainly RFID objects and sensors, (ii) a transmission layer such as fixed and mobile networks, (iii) service layer and (iv) interface layer (Lou et al. 2011; Gubbi et al. 2013; Verdouw, Beulens, and van der Vorst 2013; Borgia 2014; Xu, He, and Li 2014). The third and fourth layers are sometimes merged into one layer. Ferreira, Martinho, and Domingos (2010) defined the logistics functions of different internet of things in terms of identifying, tracing, location tracking, monitoring, real-time responsiveness and optimisation. Yuvaraj and Sangeetha (2016) combined RFID tags for indoor product tracking with GPS technology to track the same products outdoor in order to monitor the goods anywhere at any time. Yan et al. (2014) developed a new concept of Cloud of Things to facilitate resources sharing and collaborating between supply chain partners.

Some authors were interested in defining more specifically IT enablers for Industry 4.0 and smart factories concepts. Cheng et al. (2016) presented cyber–physical systems (CPS) to interconnect the physical and cyber world by integrating analogue/digital hardware and the cloud-based manufacturing (CM) characterised by its high scalability, agility, resource pooling, virtualisation, ubiquitous access, etc. Lee, Bagheri, and Kao (2015) developed a CPS architecture for manufacturing systems. Li (2016) introduced a technological framework of a smart factory in the petrochemical industry. Theorin et al. (2015) developed an event-driven information system architecture for industry 4.0 to enable flexible factory integration and data utilisation. Thoben, Wiesner, and Wuest (2017) indicated that smart manufacturing includes different technologies such as cyber–physical production systems (CPPS), IoT, robotics/automation, big data analytics and cloud computing.

Some other authors defined IoT enablers for particular SCM issues. Tao et al. (2014) designed an IoT-based framework to support the cloud manufacturing with manufacturing resource intelligent perception and access. Gnimpieba et al. (2015) used different IT enablers to set a framework for a collaborative supply chain describing data storage and real time event processing with the cloud platform. Kinnunen et al. (2016) discussed the IoT technologies related to data acquisition in industrial asset management. Karakostas (2013) suggested a Domain Names Server (DNS) architecture adapted to IoT. Singh and Gupta (2015) discussed the recent trends in intelligent transportation. Sund, Foss, and Bakas (2011) presented the intelligent goods in the intermodal freight system, which includes technologies for goods identification, sensors for status monitoring, embedded logic and communication networks. Shih and Wang (2016) developed a time–temperature indicator (TTI) for controlling the temperature of a cold supply chain using for that an IoT architecture.

In addition to IT enablers' definition, some authors raised issues and challenges related to these technologies. Haller, Karnouskos, and Schroth (2009) identified four main issues: internet scalability, identification and the addressing of billions of 'things', heterogeneity of 'things' and service paradigms. Bi, Xu, and Wang (2014) and Agrawal and Lal Das (2011) added security and privacy issues. El Khodr, Shahrestani, and Cheung (2013) raised governance and trust concerns. Finally, Atzori, Iera, and Morabito (2010) suggested paying special attention to resources efficiency in terms of computation and energy capacity besides classical scalability issues.

Overall, we noticed that the main IT enablers are still RFID objects and sensors. Many authors studied the RFID applications in supply chains. For papers published before 2010, the reader can refer to reviews by Sarac, Absi, and Dauzère-Pérès (2010), Lim, Bahr, and Leung (2013), Zhu, Mukhopadhyay, and Kurata (2012). More specifically, Chang, Klabjan, and Vossen (2010) proposed a novel approach for RFID optimal deployment in a supply chain network. Wamba (2012) conducted a study to assess the role of RFID objects as enablers for supply chain integration. In the same way, Zelbst et al. (2012) considered the impact of RFID technology on manufacturing and supply chain efficiency. Leung, Cheung, and Chu (2014) studied how to align RFID applications with supply chain strategies.

#### 4.2.2 *Source*

Sourcing is the process by which firms acquire materials and services. A successful supply chain plans its sourcing activities strategically across the supply chain. Among the strategic decisions are in-house or outsourcing, supplier selection and spend management. A supply chain should also carefully consider supplier incentives and partnership development programmes. In this section, we report on the literature that looked at IoT impacts on this important supply chain function.

Verdouw, Beulens, and van der Vorst (2013) argue that IoT enables the virtualisation of supply chains. A virtual control of supply chains allows the buyer to track and trace goods as they move through the supply chain as well as perform advanced quality control and planning. Ng et al. (2015) have proposed a model to integrate data collected from IoT into strategic planning for product assortments. One interesting idea that was proposed is to allow for product differentiation to be postponed until after delivery to the customer. Yu et al. (2015) studied the impact of IoT on supplier selection. They recommend the adoption of IoT technologies that would offer higher flexibility. Decker et al. (2008) have identified several benefits of IoT in regards to sourcing. While IoT promises to provide valuable real-time visibility to the supplier (Lou et al. 2011), it comes at a cost. Decker et al. (2008) developed a simple linear cost model to analyse the impact of the cost of sensors and alerts on the unit purchase cost.

#### 4.2.3 *Make*

A report published by the World Economic Forum in 2012 states that 'manufacturing has been immensely important to the prosperity of nations, with over 70% of the income variations of 128 nations explained by differences in manufactured product export data alone' (World Economic Forum (WEF) Deloitte Touche Tohmatsu (Firm) 2012). Historically, the evolution of manufacturing is divided into four phases known as industry 1.0 to 4.0. Each of these phases was a major shift in the manufacturing paradigm. Industry 1.0 was the introduction of mechanical production with the help of water and steam power. Industry 2.0 was mass production due to division of labour with the help of electrical energy. Industry 3.0 brought electronics, IT and control systems to the shop floor to further automate production, and now Industry 4.0 with the help of IoT is promising an unprecedented paradigm shift that will have profound implications on manufacturing and its supply chain.

Manufacturing companies have been implementing automation systems for decades. However, these systems are often organised in a hierarchical fashion within data silos. In particular, programmable logic controllers (PLC), and PC-based controllers and management systems, are largely disconnected from IT and operational systems (Lopez Research LLC 2014). Security issues being the main reason cited for these legacy structures. However, availability of data-collecting storage and analysis technology (e.g. sensors, controllers, analytics software, telemetry, Big Data and cloud computing) are providing unprecedented opportunities for smarter manufacturing.

In this review, we focus on the supply chain literature dealing with smart manufacturing and not deal with the literature focusing mainly on IT aspects. A survey on technologies in an industry 4.0 environment can be found in Lu (2017). Smart manufacturing enables smarter decisions and more efficient operations through factory and supply chain visibility based on real-time information. The areas related to the make process that can be enhanced by IoT applications include: factory visibility, connected supply chain, production planning and scheduling, proactive maintenance, quality beyond the factory, sustainability and addition to specific applications. Table 5 summarises the literature related to these areas.

#### 4.2.4 *Deliver*

The delivery function is one of the main important tasks of logistics. Logistics involves planning and control of flow and storage of goods and services (e.g. see Lummus, Krumwiede, and Vokurka 2001). Delivery in the supply chain is concerned with warehousing, order and inventory management and transportation. In Table 6, we list the major IoT impacts on the supply chain delivery processes, the technology involved and their literature sources. We note that the majority of studies focused on transportation, followed by inventory management and warehousing. There is a need for more studies to look at the impact on order management and the interface between different parties in the supply chain.

A promising area of research is that of *quality-controlled logistics (QCL).* QCL allows dynamic and real-time quality control of products as they move through the supply chain (Giannakourou and Taoukis 2003; Dada and Thiesse 2008;

Table 5. Literature summary for main areas of Make processes.

| | |
|---|---|
| *Factory visibility* | |
| Visibility and traceability framework | Wang, Zhang, and Zang (2016) |
| Ubiquitous manufacturing | Chen and Tsai (2017) |
| *Connected supply chain* | |
| Collaboration mechanisms | Schuh et al. (2014) |
| Management of innovative production networks | Veza, Mladineo, and Gjeldum (2015) |
| Highly modular multi-vendor production lines | Weyer et al. (2015) |
| Smart design and production control | Zawadzki and Żywicki (2016) |
| *Production planning and scheduling* | |
| Systematic design of the virtual factory | Choi, Kim, and Noh (2015) |
| IoT-based production performance measurement system | Hwang et al. (2016) |
| A real-time production performance analysis | Zhang et al. (2014, 2016) |
| Supply chain performance measurement approach | Dweekat, Hwang, and Park (2017) |
| Real-time scheduling | Ivanov et al. (2016) |
| Industry 4.0 elements and the lean approach | Kolberg and Zühlke (2015) |
| Predictive manufacturing systems | Lee et al. (2013) |
| Intelligent products for decentralised monitoring and control | Meyer, Wortmann, and Szirbik (2011) |
| Big data analytics for RFID logistics data | Zhong et al. (2015) |
| Smart city production system and supply chain design | Kumar et al. (2016) |
| *Proactive maintenance* | |
| Autonomous maintenance | Jasiulewicz-Kaczmarek, Saniuk, and Nowicki (2017) |
| IoT for prognostics and systems health management | |
| Predictive maintenance using data mining and smart algorithms | Kwon et al. (2016) |
| Remote monitoring and diagnosis of machines in real time | Chukwuekwe et al. (2016) |
| Computing and visualisation technologies in maintenance | Alexandru et al. (2015) |
| Application of data-driven analytics to maintenance | Roy et al. (2016) |
| Platform for real-time and automatic maintenance cloud orders | O'Donovan et al. (2015) |
| RFID technology to improve pipe inspection | Yamato, Hiroki, and Fukumoto (2016) |
| RFID value in the maintenance of aircraft | El Ghazali, Lefebvre, and Lefebvre (2013) |
| Maintenance organisations in the context of industry 4.0 | Ngai et al. (2014) |
| IoT impact on product–service systems | Bokrantz et al. (2017) |
| Predictive maintenance in accordance with industry 4.0 | Rymaszewska, Helo, and Gunasekaran (2017) |
| Maintenance in digitalised manufacturing | Spendla et al. (2017), Bokrantz et al. (2017) |
| *Quality beyond the factory* | |
| Smart objects and quality management functions | Putnik et al. (2015) |
| Zero defects by applying automatic virtual metrology | Cheng et al. (2016) |
| Challenges of Industry 4.0 for quality management | Foidl and Felderer (2016) |
| Quality management in product recovery using IoT | Ondemir and Gupta (2014) |
| Information management for supply chain quality management | Xu (2011) |
| *Sustainability* | |
| Opportunities for sustainable manufacturing in Industry 4.0 | Stock and Seliger (2016) |
| IoT-enabled system in green supply chain | Chen (2015) |
| *Applications* | |
| Customisation of mass-produced parts and Industry 4.0 | Gaub (2016) |
| RFID system for the manufacturing and assembly of crankshafts | Velandia et al. (2016) |
| Smart factory in the petrochemical industry | Li (2016) |

Jedermann and Lang 2008; Osvald and Stirn 2008; Bowman et al. 2009; Van der Vorst, Kooten, and Luning 2011; Haass et al. 2015; Lang and Jedermann 2015; Pang et al. 2015; Tadejko 2015; Bogataj, Marija, and Domen 2017; Heising, Claassen, and Dekker 2017).

Bowman et al. (2009) point to the challenge of having different sensing and measurement standards across the supply chain. The lack of compatibility between supply chain partners' IoT systems can block large amounts of data and result in a lost opportunity to use it for predictive modelling and decision-making. Sund, Foss, and Bakas (2011) looked at IoT adoption for intermodal shipping and its potential for facilitating information sharing between different modes. Verdouw, Beulens, and van der Vorst (2013) propose a conceptual framework for the use of IoT in supply chains. They argue that IoT enables the virtualisation of supply chains. Yan et al. (2014) proposed a framework for using IoT data to

Table 6. IoT impact on supply chain delivery process.

| Delivery function | IoT impact | IoT technology | Source |
|---|---|---|---|
| Warehousing | Enabler of Joint Ordering Time savings in the order of 81 to 99% | Smart things RFID tags | Lou et al. (2011), Chen, Cheng, and Huang (2013a), Chen et al. (2013b), Choy, Ho, and Lee (2017) |
| | More than 1000% savings in processing times | RFID Tags and Temperature sensors | Yan et al. (2014) |
| | Collaborative warehousing | Smart things and multi-agent systems | Reaidy, Gunasekaran, and Spalanzani (2015) |
| | Warehouse and yard management | Smart things | Tadejko (2015), Alyahya, Wang, and Bennett (2016) |
| | Safety and security | Smart things and multi-agents | Trab et al. (2015) |
| Order management | Information sharing | EPCglobal | Bowman et al. (2009) Qiu et al. (2015) |
| Inventory Management | Enabler of VMI through real time visibility | Smart things | Lou et al. (2011) |
| | Inventory shrinkage | RFID tags | Dai and Tseng (2012), Fan et al. (2014, 2015) |
| | Inventory misplacement | RFID tags | Fan et al. (2015), Mathaba et al. (2017) |
| | Shelf replenishment | RFID tags | Condea, Thiesse, and Fleisch (2012), Metzger et al. (2013) |
| | Inventory accuracy and out-of-stocks | RFID tags | Goyal et al. (2016), Cui et al. (2017), Qu et al. (2017) |
| Transportation | Positive benefits to shipper, receiver and customer, with higher benefits going to shipper | Wireless networks | Decker et al. (2008) |
| | Autonomous decision-making | Sensor Networks | Jedermann and Lang (2008) |
| | Product condition | Sensor-enabled RFID tags | Bowman et al. (2009) |
| | Quality monitoring, real-time responsiveness and price optimisation | Sensor Networks | Ferreira, Martinho, and Domingos (2010) |
| | Visibility, theft reduction | Smart items, multi-agent systems | Hribernik et al. (2010), Qu et al. (2017) |
| | Real-time visibility and joint shipping | Smart things | Lou et al. (2011) |
| | Intermodal shipping | Smart containers | Sund, Foss, and Bakas (2011), Harris, Wang, and Wang (2015) |
| | Rerouting based on quality level | Sensors, information fusion and cloud computing | Pang et al. (2015) |
| | Accurate and timely delivery | Sensor-enabled RFID networks | Xu, Yang, and Yang (2013), Kong et al. (2016), Yao (2017) |
| | More than 300% savings in scanning and recording times | RFID tags and smartphones | Yan et al. (2014) |
| | Fleet management, dynamic route optimisation | Smart things | Tadejko (2015), Haass et al. (2015) |
| | Quality control | Time-Temperature Indicator wireless sensor | Giannakourou and Taoukis (2003), Dada and Thiesse (2008), Shih and Wang (2016) |
| | Quality-controlled logistics | Smart packaging | Bogataj, Marija, and Domen (2017), Haass et al. (2015), Heising, Claassen, and Dekker (2017) |

Table 7. IoT impact on supply chain delivery decisions and models.

| | Facilities | | | Production, inventory & order management | | | | Transportation | | |
|---|---|---|---|---|---|---|---|---|---|---|
| IoT Impact | Role | Location | Capacity | Production | Frequency | Safety stock | Availability | Network design | Mode selection | Routing and scheduling |
| Condition | | | | | | | X | | | X |
| Tracking | X | X | | | | X | X | | | X |
| Costing | | | | | X | X | X | | | X |
| Pricing | | X | | | X | X | X | | | |
| Dynamic Optimisation | | | | X | | | | | | X |

exchange locations information using smartphones. Tadejko (2015) discussed the application of IoT for end-to-end visibility allowing for real-time monitoring, timely decisions and reducing delays. Qiu et al. (2015) discussed how IoT could aid in information sharing to allow for synchronisation between production and transportation. Alyahya, Wang, and Bennett (2016) have proposed a method for programming automated guided vehicles to autonomously store RFID-tagged items within warehouses.

In Table 7, we report on the potential impact of IoT on the supply chain decisions and models under the delivery function.

We note that most studies have focused on production, inventory and order management as well as vehicle routing decisions and models. In particular, there is a lack of studies that look at IoT long-term impact and models in the area of facility and supply network design as well as transportation mode selection.

#### 4.2.5 *Return*

Long before the emergence of IoT, Thierry et al. (1995) suggested putting sensors in products to record information during their life cycles to make logistics decisions. However, the idea was not promoted at that time due to technology and cost limitations. With the introduction of RFID in supply chain management, researchers started looking at its potential application in reverse logistics. Zhiduan (2005) suggested building an information-sharing platform for electronic waste recovery supply chain through electronic product code. Kiritsis (2011) introduced the idea of intelligent products and their important role in product lifecycle management. Martínez-Sala et al. (2009) proposed a solution that tracks a returnable ecological system for packaging, transport, storage and display of products over the entire supply chain.

Nativi and Lee (2012) study a manufacturer and two suppliers, one of whom is a material recycler, supply chain. They use simulation and find that using RFID increases environmental benefits and returns. Gu and Liu (2013) looked at the IoT application in the reverse logistics information management. Kiritsis (2011) modelled a closed loop product lifecycle management (PLM) using the smart product concept. The author integrated active product tracking product-embedded information device (PEID) information, PLM agent (e.g. mobile reader) and PLM system (PLM DB). Parry et al. (2016) conducted a study to demonstrate how the IoT may be operationalised to capture data on a consumer's use of products and the implications for reverse supply chains.

Paksoy et al. (2016) proposed a closed-loop supply chain model for meeting the demand of a sales and collection centre using both new and remanufactured products. The proposed model makes use of lifecycle information, which is monitored and collected using IoT technology. Xing et al. (2011) provided a design of an e-reverse logistics framework. IoT technology is used to keep product lifecycle integrity. Fang et al. (2016) proposed an integrated three-stage model based on IoT technology for the optimisation of procurement, production and product recovery, pricing and strategy of return acquisition.

Thürer et al. (2016) proposed the architecture of an IoT-driven Kanban system for solid waste collection. The proposed framework overcomes the difficulties of applying a Kanban system in this context due to a large number of collection points and geographical distances.

#### 4.2.6 *Special supply chains*

In this section, we cover the literature dealing with applications in specific areas. In particular, many papers appeared recently dealing with IoT application in the food supply chain. First, we overview three studies of general nature and then we summarise, in Table 8, the literature that focused on specific areas of the food supply chain.

Table 8. Literature relating to specific applications in the food supply chain.

| Application area | Sources |
|---|---|
| Information sharing | Yan et al. (2016), Chen (2017), Grunow and Piramuthu (2013), Bibi et al. (2017), Lorite et al. (2017), |
| Condition monitoring | Bowman et al. (2009), Jedermann et al. (2014), Badia-Melis et al. (2015), Shih and Wang (2016), |
| Food safety | Liu et al. (2016), Gautam et al. (2017), Wang and Yue (2017), |
| Virtual supply chains | Verdouw, Beulens, and van der Vorst (2013), Verdouw et al. (2016) |

Sundmaeker et al. (2016) discussed the envisaged Internet of food and farm in the year 2020. It is a path for research and technological development to develop innovative solutions that will help to feed the global population and to reduce emissions and resource usage. It can also help consumers to make an informed decision when selecting specific produce. Pang et al. (2015) presented a value-centric business–technology joint design framework. Identified benefits

Table 9. Role of IoT in supply chain management.

| Process | Role of IoT | Impact | References |
|---|---|---|---|
| Source | Link with sub-tier vendors | More visibility in supply chain, improve quality and reduce lead time | Verdouw, Beulens, and van der Vorst (2013) |
| | Real-time progress and inspection data from vendor | Better quality at lower cost | Bowman et al. (2009) |
| | Supply chain data collection | Strategic planning for suppliers selection and product assortment and differentiation | Ng et al. (2015), Yu et al. (2015) |
| Make | Visibility on more parts and raw materials | Reduce lead time and costs | Wang, Zhang, and Zang (2016) |
| | Combine product and after sales service | Increase revenue | Rymaszewska, Helo, and Gunasekaran (2017) |
| | Real-time quality and maintenance data from customer | Improve product design and time to market | Putnik et al. (2015)<br>Ondemir and Gupta (2014) |
| | Remote preventative maintenance | Increase product life and customer satisfaction | Chukwuekwe et al. (2016) |
| Deliver | Inventory tracking, information sharing and joint ordering | Significant time savings and real-time visibility; efficient use of space and resources; collaborative warehousing; timely delivery, increase inventory accuracy and reduce shrinkage and misplacement | Bowman et al. (2009), Lou et al. (2011), Chen, Cheng, and Huang (2013a), Chen et al. (2013b), Yan et al. (2014), Reaidy, Gunasekaran, and Spalanzani (2015), Qiu et al. (2015), Choy, Ho, and Lee (2017) |
| | Autonomous decision-making | Saves time, space and money | Jedermann and Lang (2008), Hribernik et al. (2010), Dai and Tseng (2012), Xu, Yang, and Yang (2013), Condea, Thiesse, and Fleisch (2012), Metzger et al. (2013), Fan et al. (2014, 2015), Haass et al. (2015), Tadejko (2015), Goyal et al. (2016), Kong et al. (2016), Mathaba et al. (2017), Cui et al. (2017), Qu et al. (2017), Yao (2017) |
| | Quality monitoring and quality-controlled logistics | Improve quality standards and reduce waste | Dada and Thiesse (2008), Bowman et al. (2009), Ferreira, Martinho, and Domingos (2010), Sund, Foss, and Bakas (2011), Giannakourou and Taoukis (2003), Harris, Wang, and Wang (2015), Pang et al. (2015), Shih and Wang (2016) |
| Return | Enhances reverse logistics | Reduce costs | Gu and Liu (2013), Kiritsis (2011) |
| | More traceability | Reduce lead time | Xing et al. (2011) |
| | Capturing product data while in use | Reduce costs | Parry et al. (2016) |
| | | Increase customer satisfaction | |

included shelf life prediction, sales premium, precision agriculture and reduction of assurance cost. They provided examples about acceleration data processing, self-learning shelf-life prediction and real-time supply chain re-planning. Lang and Jedermann (2015) presented a review of key enabling technologies for the food supply chain. In particular, they discussed the impact of sensor networks on food logistics. Noletto et al. (2017) looked at the Brazilian food supply chains current technological state and their receptivity to the Intelligent Packaging and IoT technologies adoption and noted that cost and the lack of knowledge of these technologies are the greatest barriers. Kaloxylos et al. (2013) discussed how information management in the agri-food sector would take place under a highly heterogeneous group of actors and services, based on the EU Smart Agri-Food project.

#### 4.2.7 *Other applications*

Publications reporting IoT applications in various areas include pharmaceutical supply chain (Datta 2016; Papert, Rimpler, and Pflaum 2016), retail industry (Vlachos 2014; Shin and Eksioglu 2015; Thiesse and Buckel 2015; Nowodzinski, Łukasik, and Puto 2016; Balaji and Roy 2017), construction industry ( Shin et al. 2011; Demiralp, Guven, and Ergen 2012; Dave et al. 2016; Zhong et al. 2017) and petrochemical industry (Li (2016)), among other applications.

## 5. Discussion

In this section, we provide a number of observations regarding the application of IoT in supply chain management and identify the gaps in the literature with respect to the potential of IoT in helping address supply chain management challenges.

Despite the strong interest in the IoT issue due to its huge potential and disruptive nature, applications that address supply chain challenges are still in their early stages. As mentioned in the introduction, IoT offers unprecedented visibility into all aspects of the supply chain, providing early warnings of internal and external situations that require remediation. Therefore, IoT enables firms to respond quickly to changes through effective internal operations and collaboration with suppliers and customers. Current solutions and applications are still short of unlocking this potential. We only have piecemeal applications in isolated areas with limited work that addresses the entire supply chain, as evidenced by the literature network analysis in Figure 2.

Based on our classification of the literature by supply chain processes, we found that studies are still confined to isolated areas of the supply chain. Most of the research activities are in two of the supply chain processes, namely make and deliver. In fact, there are logical explanations for this.

The roots of IoT in logistics are not new. Using technology for the tracking of objects has been around for decades through various forms of information and communication technologies. Therefore, improvements brought by IoT to the logistics function can be viewed as a continuation to previous developments. The basic logistics functions are to transport 'the right goods in the right quantity and right quality at the right time to the right place for the right price' (Decker et al. 2008). Product identification through RFID informs the system about the *right goods*. Tracing allows the detection of when items are lost and guarantees the *right quantities*. Location tracking guarantees the *right place* aspect. Monitoring the product state ensures the *right quality*. This information provides the necessary visibility that allows responsiveness to unforeseen events and taking action at the *right time* and the optimisation of the whole process.

Similarly, the roots of IoT in manufacturing go back to the 80s with various forms of automation, robotics, computer-integrated manufacturing and computer-aided manufacturing. What was computer-based then is now web-based in addition to smart objects capable of machine-to-machine communication and decision-making. What is now smart manufacturing and industry 4.0 is building on these early developments. This explains the high research activities in the 'make' supply chain process. This can also be explained by several aspects of the 'make' process that can be enhanced with IoT applications such as quality, maintenance and several aspects of internal integration as mentioned in Section 4.2.3.

Another area of great interest to both researchers and practitioners is the applications of IoT in the food supply chain. The food supply chain is an extremely challenging domain from a management perspective as it deals with perishable products and involves many actors along the chain. One-third of the food produced worldwide is lost or wasted according to the FAO (Gustavsson et al. 2011; FAO 2013). Stuart (2009) estimates that in North America and Europe, 30–50% of the food supply is discarded. In addition, food supply chains are an integral part of every economy that cannot be offshored. Thus, preventing avoidable food waste generation, food safety and efficiency throughout the food supply chain is a compelling potential of the application of IoT and explains the growing interest in this particular area. We expect that research in this area will continue to grow.

Although we did not focus on the technology aspects of IoT in our review, it is worth noting that there is a lot of research in the technology area whether software or hardware for understandable reasons since technology is the main enabler of IoT. This can be seen from the many reviews and surveys that appeared in the literature (Atzori, Iera, and Morabito 2010; Miorandi et al. 2012; Xu, He, and Li 2014; Li, Xu, and Zhao 2015; Whitmore, Agarwal, and Xu 2015; Dey et al. 2016; Mishra et al. 2016; Ng and Wakenshaw 2017).

Based on our literature review, we summarise the role and impact of IoT on major supply chain processes in Table 9. We include the four major SCOR processes: source, make, deliver and return. We list the role that IoT plays for each process as well as the impact and the corresponding references.

There are several gaps in the current literature dealing with IoT applications in SCM that can be identified from the current review. These gaps can be summarised as follows:

- Lack of solid frameworks that provide guidance of IoT adoption in a supply chain context with clear guidelines and a roadmap. These would help in advising companies as to which process and where in the supply chain would they deploy IoT, given that supply chain partners may be at different stages of the IoT implementation. In addition, these frameworks would provide help with change management practices within the company and across the supply chain.
- Lack of models that address supply chain problems in an IoT environment. Management of smart supply chains is different from that of traditional supply chains. Decision-making in an IoT context requires new tools and models that take into account this new environment, such as the abundance of big data generated from sensors and connected things. IoT will affect procurement, production planning, the management of inventory, quality and maintenance, among other issues.
- There are several barriers to the implementation of IoT in SCM from both technological and managerial perspectives. A world where all things are connected opens the door for less security and privacy (Tadejko 2015). This is especially true in a supply chain context where information sharing has always been a big challenge. Another challenge is interoperability. Research by McKinsey suggests that 40% of the value of the IoT will need to be unlocked via interoperability (Manyika et al. 2015). There is not much research addressing how to deal effectively with these challenges.

## 6. Conclusion and future research directions

In this paper, we provided an account of the latest developments in the application of IoT to various supply chain processes and areas of supply chain management. As such, we explored IoT in an SCM context, presented its main technology enablers and provided an IoT definition in an SCM context. We organised IoT applications around key supply chain processes. We provided a bibliometric analysis of a representative body of literature up to mid-2017. We identified the gaps in the literature with respect to the potential of IoT role in helping address supply chain management challenges. The aim is to provide an informative overview of the latest development in this emerging and growing area, which is of interest to both researchers and practitioners.

We conclude this paper by pointing out several possible venues for future research. Below we describe some possibilities, with a focus on modelling and optimisation in different application area:

- *Maintenance*: Two research questions are relevant in the area of maintenance. First, what is the optimal placement of sensors and alert initiation? Second, with the predominance of ‘smart’ items what is the optimal scheduling of autonomous repair operations? Other interesting topics include looking at optimal inspection under discrete monitoring sensors and condition-based maintenance analytics (Bowman et al. 2009). Finally, an important research topic is exception analytics: How do we decide an exception is serious enough to take a certain action?
- *Virtual Network Flow Design and Optimisation*: Virtualisation of supply chains is making it possible to decouple physical flow from coordination and planning (e.g. Verdouw, Beulens, and van der Vorst 2013). It thus becomes a challenge to optimise flow in virtual supply networks that dynamically change their configuration depending on the state of the physical supply chain system.
- *Costing*: An important question for firms is the costing of IoT technology. For example, how to best determine the economic and ecological value of sensor information (Bowman et al. 2009)?
- *Vehicle routing*: Real-time tracking and re-optimisation of routing and schedules will be a daily reality in the IoT age. For example, how to re-optimise routes in humanitarian logistics, where some routes/truck may be interdicted, or in food supply chains, where products could be rerouted based on their quality level, as alluded to by Pang et al. (2015)?

- *Quality-controlled logistics*: Quality-controlled logistics for perishable goods that incorporates decisions from suppliers to issue replacement shipments, engineers to perform corrections (Bowman et al. 2009, p 19) as well as the possibility of customers looking for an alternative source. As in Heising, Claassen, and Dekker (2017), an interesting question is looking at joint optimal quality and pricing in food supply chain logistics where expiry dates may be dynamic. An important application is in perishable goods monitoring analytics (Bowman et al. 2009) that looks at both supply and demand aspects. For the supply of perishable products, we would consider the material composition, physical changes, environmental factors (such as temperature, humidity, gas concentrations and shock) and chemical reactions. For demand, we would take into account several measures such as aesthetic appearance, texture, flavour and nutritional value.

## Acknowledgement

The authors are grateful to four reviewers for their careful reading of the paper and their valuable feedback.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This work was supported by American University of Sharjah; Natural Sciences and Engineering Research Council of Canada.

## References

Agrawal, S., and M. Lal Das. 2011. "Internet of Things – A Paradigm Shift of Future Internet Applications." In *2011 Nirma University International Conference on Engineering*. Ahmedabad, India.

Alexandru, A. M., A. De Mauro, M. Fiasche, F. G. Sisca, M. Taisch, L. Fasanotti, and P. Grasseni. 2015. "A Smart Web-Based Maintenance System for a Smart Manufacturing Environment." In *2015 IEEE 1st International Forum on Research and Technologies for Society and Industry Leveraging a Better Tomorrow (RTSI)*. Torino, Italy.

Alyahya, S., Q. Wang, and N. Bennett. 2016. "Application and Integration of an RFID-Enabled Warehousing Management System – A Feasibility Study." *Journal of Industrial Information Integration* 4: 15–25.

Angeles, R. 2005. "Rfid Technologies: Supply-Chain Applications and Implementation Issues." *Information Systems Management* 22 (1): 51–65.

APICS. 2015. "Supply Chain Operations Reference Model, Revision 11.0." http://www.apics.org/docs/default-source/scor-p-toolkits/apics-scc-scor-quick-reference-guide.pdf?sfvrsn=2.

Atzori, L., A. Iera, and G. Morabito. 2010. "The Internet of Things: A Survey." *Computer Networks* 54 (15): 2787–2805.

Badia-Melis, R., L. Ruiz-Garcia, J. Garcia-Hierro, and J. Villalba. 2015. "Refrigerated Fruit Storage Monitoring Combining Two Different Wireless Sensing Technologies: RFID and WSN." *Sensors* 15 (3): 4781–4795.

Balaji, M. S., and S. K. Roy. 2017. "Value Co-Creation with Internet of Things Technology in the Retail Industry." *Journal of Marketing Management* 33 (1–2): 7–31.

Barratt, M., and A. Oke. 2007. "Antecedents of Supply Chain Visibility in Retail Supply Chains: A Resource-Based Theory Perspective." *Journal of Operations Management* 25 (6): 1217–1233.

Bi, Z., L. D. Xu, and C. Wang. 2014. "Internet of Things for Enterprise Systems of Modern Manufacturing." *IEEE Transactions on Industrial Informatics* 10 (2): 1537–1546.

Bibi, F., C. Guillaume, N. Gontard, and B. Sorli. 2017. "A Review: RFID Technology Having Sensing Aptitudes for Food Industry and Their Contribution to Tracking and Monitoring of Food Products." *Trends in Food Science & Technology* 62: 91–103.

Bogataj, D., B. Marija, and H. Domen. 2017. "Mitigating Risks of Perishable Products in the Cyber-Physical Systems Based on the Extended MRP Model." *International Journal of Production Economics* 193: 51–62.

Bokrantz, J., A. Skoogh, C. Berlin, and J. Stahre. 2017. "Maintenance in Digitalised Manufacturing: Delphi-Based Scenarios for 2030." *International Journal of Production Economics* 191: 154–169.

Bonomi, F., R. Milito, J. Zhu, and S. Addepalli. 2012. "Fog Computing and Its Role in the Internet of Things." In *Proceedings of the First Edition of the MCC Workshop on Mobile Cloud Computing - MCC 12*. Helsinki, Finland.

Bonomi, F., R. Milito, P. Natarajan, and J. Zhu. 2014. "Fog Computing: A Platform for Internet of Things and Analytics." In *Big Data and Internet of Things: A Roadmap for Smart Environments*, edited by N. Bessis, and C. Dobre, Vol. 546, 169–186. Studies in Computational Intelligence. Cham: Springer.

Borgia, E. 2014. "The Internet of Things Vision: Key Features, Applications and Open Issues." *Computer Communications* 54: 1–31.

Bowman, P., J. Ng, M. Harisson, T. Sanchez Lopez, and A. Illic. 2009. "Sensor Based Condition Monitoring." Building Radio Frequency Identification for the Global Environment (Bridge) Euro RFID Project. http://bridge-project.eu/index.php/mainpage/en/

Butner, K. 2010. “The Smarter Supply Chain of the Future.” *Strategy & Leadership* 38 (1): 22–31.

Chang, S., D. Klabjan, and T. Vossen. 2010. “Optimal Radio Frequency Identification Deployment in a Supply Chain Network.” *International Journal of Production Economics* 125 (1): 71–83.

Chen, R. Y. 2015. “Intelligent IoT-Enabled System in Green Supply Chain Using Integrated FCM Method.” *International Journal of Business Analytics* 2 (3): 47–66.

Chen, R. Y. 2017. “An Intelligent Value Stream-Based Approach to Collaboration of Food Traceability Cyber Physical System by Fog Computing.” *Food Control* 71: 124–136.

Chen, T., and H. R. Tsai. 2017. “Ubiquitous Manufacturing: Current Practices, Challenges, and Opportunities.” *Robotics and Computer-Integrated Manufacturing* 45: 126–132.

Chen, J. C., C. H. Cheng, and P. B. Huang. 2013a. “Supply Chain Management with Lean Production and RFID Application: A Case Study.” *Expert Systems with Applications* 40 (9): 3389–3397.

Chen, J. C., C. H. Cheng, P. B. Huang, K. J. Wang, C. J. Huang, and T. C. Ting. 2013b. “Warehouse Management with Lean and RFID Application: A Case Study.” *The International Journal of Advanced Manufacturing Technology* 69 (1–4): 531–542.

Cheng, F. T., H. Tieng, H. C. Yang, M. H. Hung, Y. C. Lin, C. F. Wei, and Z. Y. Shieh. 2016. “Industry 4.1 for Wheel Machining Automation.” *IEEE Robotics and Automation Letters* 1 (1): 332–339.

Choi, S., B. H. Kim, and S. D. Noh. 2015. “A Diagnosis and Evaluation Method for Strategic Planning and Systematic Design of a Virtual Factory in Smart Manufacturing Systems.” *International Journal of Precision Engineering and Manufacturing* 16 (6): 1107–1115.

Chopra, S., and P. Meindl. 2013. *Supply Chain Management: Strategy, Planning, and Operation*. Chapter 1, 5th ed. Harlow: Pearson. www.pearson.com.

Choy, K. L., G. T. S. Ho, and C. K. H. Lee. 2017. “A RFID-Based Storage Assignment System for Enhancing the Efficiency of Order Picking.” *Journal of Intelligent Manufacturing* 28 (1): 111–129.

Christopher, M. 2016. *Logistics & Supply Chain Management*. Harlow: Pearson. www.pearson.com.

Christopher, M., and M. Holweg. 2011. “‘Supply Chain 2.0’: Managing Supply Chains in the Era of Turbulence.” *International Journal of Physical Distribution & Logistics Management* 41 (1): 63–82.

Chukwuekwe, D. O., P. Schjølberg, H. Rødseth, and A. Stuber. 2016. “Reliable, Robust and Resilient Systems: Towards Development of a Predictive Maintenance Concept within the Industry 4.0 Environment.” EFNMS Euro Maintenance Conference, Athens, Greece.

Colicchia, C., and F. Strozzi. 2012. “Supply Chain Risk Management: A New Methodology for a Systematic Literature Review.” *Supply Chain Management: An International Journal* 17 (4): 403–418.

Condea, C., F. Thiesse, and E. Fleisch. 2012. “RFID-Enabled Shelf Replenishment with Backroom Monitoring in Retail Stores.” *Decision Support Systems* 52 (4): 839–849.

Cui, L., J. Deng, F. Liu, Y. Zhang, and M. Xu. 2017. “Investigation of RFID Investment in a Single Retailer Two-Supplier Supply Chain with Random Demand to Decrease Inventory Inaccuracy.” *Journal of Cleaner Production* 142: 2028–2044.

Dada, A., and F. Thiesse. 2008. “Sensor Applications in the Supply Chain: The Example of Quality-Based Issuing of Perishables.” *The Internet of Things Lecture Notes in Computer Science* 4952: 140–154.

Dai, H., and M. M. Tseng. 2012. “The Impacts of RFID Implementation on Reducing Inventory Inaccuracy in a Multi-Stage Supply Chain.” *International Journal of Production Economics* 139 (2): 634–641.

Datta, S. P. A. 2016. “Retail Medicine in an Era of IoT and Medical Errors in the Age of Ubiquitous Connectivity.” *Journal of Innovation Management* 4 (3): 3–6.

Dave, B., S. Kubler, K. Främling, and L. Koskela. 2016. “Opportunities for Enhanced Lean Construction Management Using Internet of Things Standards.” *Automation in Construction* 61: 86–97.

Decker, C., M. Berchtold, L. W. F. Chaves, M. Beigl, D. Roehr, T. Riedel, M. Beuster, T. Herzog, and D. Herzig. 2008. “Cost-Benefit Model for Smart Items in the Supply Chain.” *The Internet of Things Lecture Notes in Computer Science* 4952: 155–172.

Demiralp, G., G. Guven, and E. Ergen. 2012. “Analyzing the Benefits of RFID Technology for Cost Sharing in Construction Supply Chains: A Case Study on Prefabricated Precast Components.” *Automation in Construction* 24: 120–129.

Dey, S., S. D. Joshi, S. Patil, B. Kumar, and V. A. Kagi. 2016. “A Survey of the Internet of Things.” *IOSR Journal of Computer Engineering* 18 (1): 80–85.

Dorsemaine, B., J. P. Gaulier, J. P. Wary, N. Kheir, and P. Urien. 2015. “Internet of Things: A Definition & Taxonomy.” 9th International Conference on Next Generation Mobile Applications, Services and Technologies, Cambridge, UK.

Dweekat, A. J., G. Hwang, and J. Park. 2017. “Supply Chain Performance Measurement Approach Using the Internet of Things.”*Industrial Management & Data Systems* 117 (2): 267–286.

El Ghazali, Y., E. Lefebvre, and L. A. Lefebvre. 2013. “Intelligent Inspection Processes for Intelligent Maintenance: The Potential of RFID in the Petroleum Industry.” *International Journal of Construction Engineering and Management* 2 (4): 93–105.

El Khodr, M., S. Shahrestani, and H. Cheung. 2013. “The Internet of Things: Vision and Challenges.” In *TENCON Spring Conference, 2013 IEEE*, April 2013. Sydney, Australia, 218–222.

Ellis, S., H. D. Morris, and J. Santagate. 2015. “IoT-Enabled Analytic Applications Revolutionize Supply Chain Planning and Execution.” International Data Corporation (IDC) White Paper. www.idc.com.

Fahimnia, B., J. Sarkis, and H. Davarzani. 2015. "Green Supply Chain Management: A Review and Bibliometric Analysis." *International Journal of Production Economics* 162: 101–114.

Fan, T. J., X. Y. Chang, C. H. Gu, J. J. Yi, and S. Deng. 2014. "Benefits of RFID Technology for Reducing Inventory Shrinkage." *International Journal of Production Economics* 147: 659–665.

Fan, T., F. Tao, S. Deng, and S. Li. 2015. "Impact of RFID Technology on Supply Chain Decisions with Inventory Inaccuracies." *International Journal of Production Economics* 159: 117–125.

Fang, C., X. Liu, P. M. Pardalos, and J. Pei. 2016. "Optimization for a Three-Stage Production System in the Internet of Things: Procurement, Production and Product Recovery, and Acquisition." *The International Journal of Advanced Manufacturing Technology* 83 (5–8): 689–710.

FAO. 2013. *Food Wastage Footprint*. Rome: FAO.

Ferreira, P., R. Martinho, and D. Domingos. 2010. "IoT-Aware Business Processes for Logistics: Limitations of Current Approaches." In *INForum 2010 – II Simposio de Informatica, Braga; 2010*, September 9–10, edited by L. S. Barbosa and M. P. Correia, 611–622.

Foidl, H., and M. Felderer. 2016. "Research Challenges of Industry 4.0 for Quality Management." In *Innovations in Enterprise Information Systems Management and Engineering Lecture Notes in Business Information Processing*, Munich, Germany, 121–137.

Fortino, G., and P. Trunfio. 2014. Preface of *Internet of Things based on Smart Objects: Technology, Middleware and Applications*, edited by G. Fortino and P. Trunfio. Cham: Springer.

Gaub, H. 2016. "Customization of Mass-Produced Parts by Combining Injection Molding and Additive Manufacturing with Industry 4.0 Technologies." *Reinforced Plastics* 60 (6): 401–404.

Gaukler, G. M., R. W. Seifert, and W. H. Hausman. 2007. "Item-Level RFID in the Retail Supply Chain." *Production and Operations Management* 16 (1): 65–76.

Gautam, R., A. Singh, K. Karthik, S. Pandey, F. Scrimgeour, and M. K. Tiwari. 2017. "Traceability Using RFID and Its Formulation for a Kiwifruit Supply Chain." *Computers & Industrial Engineering* 103: 46–58.

Giannakourou, M. C., and P. S. Taoukis. 2003. "Application of a TTI-Based Distribution Management System for Quality Optimization of Frozen Vegetables at the Consumer End." *Journal of Food Science* 68 (1): 201–209.

Gnimpieba, Z. D. R., A. Nait-Sidi-Moh, D. Durand, and J. Fortin. 2015. "Using Internet of Things Technologies for a Collaborative Supply Chain: Application to Tracking of Pallets and Containers." *Procedia Computer Science* 56: 550–557.

Goyal, S., B. C. Hardgrave, J. A. Aloysius, and N. DeHoratius. 2016. "The Effectiveness of RFID in Backroom and Sales Floor Inventory Management." *The International Journal of Logistics Management* 27 (3): 795–815.

Greengard, S. 2015. *The Internet of Things*. Cambridge, MA: MIT Press.

Grunow, M., and S. Piramuthu. 2013. "RFID in Highly Perishable Food Supply Chains – Remaining Shelf Life to Supplant Expiry Date?" *International Journal of Production Economics* 146 (2): 717–727.

Gu, Y., and Q. Liu. 2013. "Research on the Application of the Internet of Things in Reverse Logistics Information Management." *Journal of Industrial Engineering and Management* 6 ( 4): 963–973.

Gubbi, J., R. Buyya, S. Marusic, and M. Palaniswami. 2013. "Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions." *Future Generation Computer Systems* 29 (7): 1645–1660.

Gustavsson, J., C. Cederberg, U. Sonesson, R. V. Otterdijk, and A. Meybeck. 2011. *Global Food Losses and Food Waste*, 1–38. Rome: FAO.

Haass, R., P. Dittmer, M. Veigt, and M. Lütjen. 2015. "Reducing Food Losses and Carbon Emission by Using Autonomous Control-a Simulation Study of the Intelligent Container." *International Journal of Production Economics* 164: 400–408.

Haller, S., S. Karnouskos, and C. Schroth. 2009. "The Internet of Things in an Enterprise Context." In *Lecture Notes in Computer Science Future Internet – FIS 2008*, Vol. 5468, 14–28. Berlin, Germany.

Harris, I., Y. Wang, and H. Wang. 2015. "ICT in Multimodal Transport and Technological Trends: Unleashing Potential for the Future." *International Journal of Production Economics* 159: 88–103.

Hassini, E. 2008. "Supply Chain Optimization: Current Practices and Overview of Emerging Research Opportunities." *INFOR: Information Systems and Operational Research* 46 (2): 93–96.

Heese, H. S. 2007. "Inventory Record Inaccuracy, Double Marginalization, and RFID Adoption." *Production and Operations Management* 16 (5): 542–553.

Heising, J. K., G. D. H. Claassen, and M. Dekker. 2017. "Options for Reducing Food Waste by Quality-Controlled Logistics using Intelligent Packaging along the Supply Chain. " *Food Additives & Contaminants: Part A* 34 (10):1672–1680.

Hribernik, K. A., T. Warden, K. D. Thoben, and O. Herzog. 2010. "An Internet of Things for Transport Logistics–an Approach to Connecting the Information and Material Flows in Autonomous Cooperating Logistics Processes." In *Proceedings of the 12th International MITIP Conference on Information Technology & Innovation Processes of the Enterprises*, Aalborg, Denmark, 54–67.

Hwang, G., J. Lee, J. Park, and T. W. Chang. 2016. "Developing Performance Measurement System for Internet of Things and Smart Factory Environment." *International Journal of Production Research* 55 (9): 2590–2602.

Information Society and Media Directorate General of the European Commission (INFSO). 2008. "Internet of Things in 2020 - Roadmap for the Future." Accessed August 2017. https://www.smart-systems-integration.org/public/documents/publications/Internet-of-Things_in_2020_EC-EPoSS_Workshop_Report_2008_v3.pdf/download.

Ivanov, D., A. Dolgui, B. Sokolov, F. Werner, and M. Ivanova. 2016. "A Dynamic Model and an Algorithm for Short-Term Supply Chain Scheduling in the Smart Factory Industry 4.0." *International Journal of Production Research* 54 (2): 386–402.

Jasiulewicz-Kaczmarek, M., A. Saniuk, and T. Nowicki. 2017. "The Maintenance Management in the Macro-Ergonomics Context." *Advances in Intelligent Systems and Computing Advances in Social & Occupational Ergonomics* 487: 35–46.

Jedermann, R., and W. Lang. 2008. "The Benefits of Embedded Intelligence – Tasks and Applications for Ubiquitous Computing in Logistics." *The Internet of Things Lecture Notes in Computer Science* 4952: 105–122.

Jedermann, R., M. Nicometo, I. Uysal, and W. Lang. 2014. "Reducing Food Losses by Intelligent Food Logistics." *Philosophical Transactions of the Royal Society a: Mathematical, Physical and Engineering Sciences* 372 (2017): 20130302.

Kagermann, H., W. Wahlster, and J. Helbig. 2013. "Recommendations for Implementing the Strategic Initiative Industrie 4.0: Final Report of the Industrie 4.0 Working Group." Acatech-National Academy of Science and Engineering, Munich, Germany.

Kaloxylos, A., J. Wolfert, T. Verwaart, C. M. Terol, C. Brewster, R. Robbemond, and H. Sundmaker. 2013. "The Use of Future Internet Technologies in the Agriculture and Food Sectors: Integrating the Supply Chain." *Procedia Technology* 8: 51–60.

Karakostas, B. 2013. "A DNS Architecture for the Internet of Things: A Case Study in Transport Logistics." *Procedia Computer Science* 19: 594–601.

Kinnunen, S. K., S. Marttonen-Arola, A. Ylä-Kujala, T. Kärri, T. Ahonen, P. Valkokari, and D. Baglee. 2016. "Decision Making Situations Define Data Requirements in Fleet Asset Management." In *Proceedings of the 10th World Congress on Engineering Asset Management (WCEAM 2015) Lecture Notes in Mechanical Engineering*, Tampere, Finland, 357–364.

Kiritsis, D. 2011. "Closed-Loop PLM for Intelligent Products in the Era of the Internet of Things." *Computer-Aided Design* 43 (5): 479–501.

Kolberg, D., and D. Zühlke. 2015. "Lean Automation Enabled by Industry 4.0 Technologies." *IFAC-PapersOnLine* 48 (3): 1870–1875.

Kong, X. T. R., J. Chen, H. Luo, and G. Q. Huang. 2016. "Scheduling at an Auction Logistics Centre with Physical Internet." *International Journal of Production Research* 54 (9): 2670–2690.

Kumar, M., G. Graham, P. Hennelly, and J. Srai. 2016. "How Will Smart City Production Systems Transform Supply Chain Design: A Product-Level Investigation." *International Journal of Production Research* 54 (23): 7181–7192.

Kwon, D., M. R. Hodkiewicz, J. Fan, T. Shibutani, and M. G. Pecht. 2016. "IoT-Based Prognostics and Systems Health Management for Industrial Applications." *IEEE Access* 4: 3659–3670.

Lambert, D. M., and M. C. Cooper. 2000. "Issues in Supply Chain Management." *Industrial Marketing Management* 29 (1): 65–83.

Lang, W., and R. Jedermann. 2015. "The Intelligent Container - What can MEMS do for Logistics of Food?" In *Proc. IEEE SENSORS*, Busan, Korea, 1–4.

Lee, I., and K. Lee. 2015. "The Internet of Things (IoT): Applications, Investments, and Challenges for Enterprises." *Business Horizons* 58 (4): 431–440.

Lee, J., E. Lapira, B. Bagheri, and H. A. Kao. 2013. "Recent Advances and Trends in Predictive Manufacturing Systems in Big Data Environment." *Manufacturing Letters* 1 (1): 38–41.

Lee, J., B. Bagheri, and H. A. Kao. 2015. "A Cyber-Physical Systems Architecture for Industry 4.0-Based Manufacturing Systems." *Manufacturing Letters* 3: 18–23.

Leung, J., W. Cheung, and S. C. Chu. 2014. "Aligning RFID Applications with Supply Chain Strategies." *Information & Management* 51 (2): 260–269.

Li, D. 2016. "Perspective for Smart Factory in Petrochemical Industry." *Computers & Chemical Engineering* 91: 136–148.

Li, S., L. Xu, X. Wang, and J. Wang. 2012. "Integration of Hybrid Wireless Networks in Cloud Services Oriented Enterprise Information Systems." *Enterprise Information Systems* 6 (2): 165–187.

Li, S., L. D. Xu, and S. Zhao. 2015. "The Internet of Things: A Survey." *Information Systems Frontiers* 17 (2): 243–259.

Liao, Y., F. Deschamps, E. D. F. R. Loures, and L. F. P. Ramos. 2017. "Past, Present and Future of Industry 4.0 - a Systematic Literature Review and Research Agenda Proposal." *International Journal of Production Research* 55 (12): 3609–3629.

Lim, M. K., W. Bahr, and S. C. H. Leung. 2013. "RFID in the Warehouse: A Literature Analysis (1995–2010) of Its Applications, Benefits, Challenges and Future Trends." *International Journal of Production Economics* 145 (1): 409–430.

Liu, Y., W. Han, Y. Zhang, L. Li, J. Wang, and L. Zheng. 2016. "An Internet-of-Things Solution for Food Safety and Quality Control: A Pilot Project in China." *Journal of Industrial Information Integration* 3: 1–7.

Liu, F., C. W. Tan, E. T. K. Lim, and B. Choi. 2017. "Traversing Knowledge Networks: An Algorithmic Historiography of Extant Literature on the Internet of Things (IoT)." *Journal of Management Analytics* 4 (1): 3–34.

Lopez Research LLC. 2014. *Building Smarter Manufacturing with the Internet of Things (IoT): Part 2 of the IoT Series*. San francisco, CA: Lopez Research LLC. www.lopezresearch.com

López, T. S., D. C. Ranasinghe, B. Patkai, and D. McFarlane. 2011. "Taxonomy, Technology and Applications of Smart Objects." *Information Systems Frontiers* 13 (2): 281–300.

Lorite, G. S., T. Selkälä, T. Sipola, J. Palenzuela, E. Jubete, A. Viñuales, G. Cabañero, et al. 2017. "Novel, Smart and RFID Assisted Critical Temperature Indicator for Supply Chain Monitoring." *Journal of Food Engineering* 193: 20–28.

Lou, P., Q. Liu, Z. Zhou, and H. Wang. 2011. "Agile Supply Chain Management over the Internet of Things." *2011 International Conference on Management and Service Science*.

Lu, Y. 2017. “Industry 4.0: A Survey on Technologies, Applications and Open Research Issues.” *Journal of Industrial Information Integration* 6: 1–10.

Lummus, R. R., D. W. Krumwiede, and R. J. Vokurka. 2001. “The Relationship of Logistics to Supply Chain Management: Developing a Common Industry Definition.” *Industrial Management & Data Systems* 101 (8): 426–432.

Manyika, J., J. Woetzel, R. Dobbs, M. Chui, P. Bisson, J. Bughin, and D. Aharon. 2015. *The Internet of Things: Mapping the Value Beyond the Hype*. McKinsey Global Institute.

M&S Consulting. 2017. “Industrial Internet of Things Platform Comparison.” Accessed October 5, 2017. https://www.mandsconsulting.com/industrial-iot-platform-comparison

Martínez-Sala, A. S., E. Egea-López, F. García-Sánchez, and J. García-Haro. 2009. “Tracking of Returnable Packaging and Transport Units with Active RFID in the Grocery Supply Chain.” *Computers in Industry* 60 (3): 161–171.

Mathaba, S., M. Adigun, J. Oladosu, and O. Oki. 2017. “On the Use of the Internet of Things and Web 2.0 in Inventory Management.” *Journal of Intelligent & Fuzzy Systems* 32 (4): 3091–3101.

Metzger, C., F. Thiesse, S. Gershwin, and E. Fleisch. 2013. “The Impact of False-Negative Reads on the Performance of RFID-Based Shelf Inventory Control Policies.” *Computers & Operations Research* 40 (7): 1864–1873.

Meyer, G. G., K. Främling, and J. Holmström. 2009. “Intelligent Products: A Survey.” *Computers in Industry* 60 (3): 137–148.

Meyer, G. G., J. C. H. Wortmann, and N. B. Szirbik. 2011. “Production Monitoring and Control with Intelligent Products.” *International Journal of Production Research* 49 (5): 1303–1317.

Miorandi, D., S. Sicari, F. De Pellegrini, and I. Chlamtac. 2012. “Internet of Things: Vision, Applications and Research Challenges.” *Ad Hoc Networks* 10 (7): 1497–1516.

Mishra, D., A. Gunasekaran, S. J. Childe, T. Papadopoulos, R. Dubey, and S. Wamba. 2016. “Vision, Applications and Future Challenges of Internet of Things.” *Industrial Management & Data Systems* 116 (7): 1331–1355.

Musa, A., and A. A. A. Dabo. 2016. “A Review of RFID in Supply Chain Management: 2000–2015.” *Global Journal of Flexible Systems Management* 17 (2): 189–228.

Naskar, S, P. Basu, and A. K. Sen. 2017. “A Literature Review of the Emerging Field of IoT Using RFID and Its Applications in Supply Chain Management.” In *The Internet of Things in the Modern Business Environment Advances in E-Business Research*, 1–27. Hershey, PA: IGI Global.

Nativi, J. J., and S. Lee. 2012. “Impact of RFID Information-Sharing Strategies on a Decentralized Supply Chain with Reverse Logistics Operations.” *International Journal of Production Economics* 136 (2): 366–377.

Ng, I. C. L., and S. Wakenshaw. 2017. “The Internet-of-Things: Review and Research Directions.” *International Journal of Research in Marketing* 34 (1): 3–21.

Ng, I., K. Scharf, G. Pogrebna, and R. Maull. 2015. “Contextual Variety, Internet-of-Things and the Choice of Tailoring over Platform: Mass Customisation Strategy in Supply Chain Management.” *International Journal of Production Economics* 159: 76–87.

Ngai, E. W. T., B. K. S. Cheung, S. S. Lam, and C. T. Ng. 2014. “RFID Value in Aircraft Parts Supply Chains: A Case Study.” *International Journal of Production Economics* 147: 330–339.

Noletto, A. P. R., S. A. Loureiro, R. B. Castro, and O. F. L. Júnior. 2017. “Intelligent Packaging and the Internet of Things in Brazilian Food Supply Chains: The Current State and Challenges.” In *Dynamics in Logistics. Lecture Notes in Logistics*, edited by M. Freitag, H. Kotzab, and J. Pannekm, 173–183. Cham: Springer.

Nowodzinski, P., K. Łukasik, and A. Puto. 2016. “Internet of Things (IoT) in a Retail Environment. the New Strategy for Firm's Development.” *European Scientific Journal, ESJ* 12 (10): 332–341.

O'Donovan, P., K. Leahy, K. Bruton, and D. T. J. O'Sullivan. 2015. “An Industrial Big Data Pipeline for Data-Driven Analytics Maintenance Applications in Large-Scale Smart Manufacturing Facilities.” *Journal of Big Data* 2 (1): 1–26.

Ondemir, O., and S. M. Gupta. 2014. “Quality Management in Product Recovery Using the Internet of Things: An Optimization Approach.” *Computers in Industry* 65 (3): 491–504.

Osvald, A., and L. Z. Stirn. 2008. “A Vehicle Routing Algorithm for the Distribution of Fresh Vegetables and Similar Perishable Food.” *Journal of Food Engineering* 85 (2): 285–295.

Paksoy, T., I. Karaoglan, H. Gökçen, P. Pardalos, and B. Torgul. 2016. “An Experimental Research on Closed Loop Supply Chain Management with Internet of Things.” *Journal of Economics Bibliography* 3 (1S): 1–20.

Pang, Z., Q. Chen, W. Han, and L. Zheng. 2015. “Value-Centric Design of the Internet-of-Things Solution for Food Supply Chain: Value Creation, Sensor Portfolio and Information Fusion.” *Information Systems Frontiers* 17 (2): 289–319.

Papert, M., P. Rimpler, and A. Pflaum. 2016. “Enhancing Supply Chain Visibility in a Pharmaceutical Supply Chain.” *International Journal of Physical Distribution & Logistics Management* 46 (9): 859–884.

Parry, G. C., S. A. Brax, R. S. Maull, and I. C. L. Ng. 2016. “Operationalising IoT for Reverse Supply: The Development of Use-Visibility Measures.” *Supply Chain Management: An International Journal* 21 (2): 228–244.

Persson, O., R. Danell and J. W. Schneider. 2009. “How to Use Bibexcel for Various Types of Bibliometric Analysis.” *Celebrating Scholarly Communication Studies: A Festschrift for Olle Persson at His 60th Birthday* 5: 9–24.

Postcapes. 2017. “IoT Standards and Protocols.” Accessed September 28, 2017. https://www.postscapes.com/internet-of-things-protocols/

Putnik, G., L. R. Varela, C. Carvalho, C. Alves, V. Shah, H. Castro, and P. Ávila. 2015. "Smart Objects Embedded Production and Quality Management Functions." *International Journal for Quality Research* 9 (1): 151–166.

Qiu, X., H. Luo, G. Xu, R. Zhong, and G. Q. Huang. 2015. "Physical Assets and Service Sharing for IoT-Enabled Supply Hub in Industrial Park (SHIP)." *International Journal of Production Economics* 159: 4–15.

Qu, T., M. Thürer, J. Wang, Z. Wang, H. Fu, C. Li, and G. Q. Huang. 2017. "System Dynamics Analysis for an Internet-of-Things-Enabled Production Logistics System." *International Journal of Production Research* 55 (9): 2622–2649.

Rayes, A., and S. Salam. 2016. "The Things in IoT: Sensors and Actuators." In *Internet of Things From Hype to Reality*. Cham: Springer.

Reaidy, P. J., A. Gunasekaran, and A. Spalanzani. 2015. "Bottom-up Approach Based on Internet of Things for Order Fulfillment in a Collaborative Warehousing Environment." *International Journal of Production Economics* 159: 29–40.

Ross, D. F. 2016. *Introduction to Supply Chain Management Technologies*. Boca Raton, FL: St Lucie Press.

Roy, R., R. Stark, K. Tracht, S. Takata, and M. Mori. 2016. "Continuous Maintenance and the Future – Foundations and Technological Challenges." *CIRP Annals – Manufacturing Technology* 65 (2): 667–688.

Rymaszewska, A., P. Helo, and A. Gunasekaran. 2017. "IoT Powered Servitization of Manufacturing – An Exploratory Case Study." *International Journal of Production Economics* 192: 92–105.

Sarac, A., N. Absi, and S. Dauzère-Pérès. 2010. "A Literature Review on the Impact of RFID Technologies on Supply Chain Management." *International Journal of Production Economics* 128 (1): 77–95.

Schuh, G., T. Potente, C. Wesch-Potente, A. R. Weber, and J. P. Prote. 2014. "Collaboration Mechanisms to Increase Productivity in the Context of Industrie 4.0." *Procedia CIRP* 19: 51–56.

Shih, C. W., and C. H. Wang. 2016. "Integrating Wireless Sensor Networks with Statistical Quality Control to Develop a Cold Chain System in Food Industries." *Computer Standards & Interfaces* 45: 62–78.

Shin, S., and B. Eksioglu. 2015. "An Empirical Study of RFID Productivity in the U.S. Retail Supply Chain." *International Journal of Production Economics* 163: 89–96.

Shin, T. H., S. Chin, S. W. Yoon, and S. W. Kwon. 2011. "A Service-Oriented Integrated Information Framework for RFID/WSN-Based Intelligent Construction Supply Chain Management." *Automation in Construction* 20 (6): 706–715.

Simchi-Levi, D., P. Kaminsky, and E. S. Levi. 2003. *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies*. New York: McGraw-Hill.

Singh, B., and A. Gupta. 2015. "Recent Trends in Intelligent Transportation Systems: A Review." *Journal of Transport Literature* 9 (2): 30–34.

Spendla, L., M. Kebisek, P. Tanuska, and L. Hrcka. 2017. "Concept of Predictive Maintenance of Production Systems in Accordance with Industry 4.0." 2017 IEEE 15th International Symposium on Applied Machine Intelligence and Informatics (SAMI), Herl'any, Slovakia.

Srivastava, S. K. 2007. "Green Supply-Chain Management: A State-of-the-Art Literature Review." *International Journal of Management Reviews* 9 (1): 53–80.

Stock, T., and G. Seliger. 2016. "Opportunities of Sustainable Manufacturing in Industry 4.0." *Procedia CIRP* 40: 536–541.

Strozzi, F., C. Colicchia, A. Creazza, and C. Noè. 2017. "Literature Review on the 'Smart Factory' Concept Using Bibliometric Tools." *International Journal of Production Research* 11: 1–20.

Stuart, T. 2009. *Waste. Uncovering the Global Food Scandal*. London: Penguin.

Sund, A. B., T. Foss, and O. Bakas. 2011. "Intelligent Goods in the Intermodal Freight System." European Transport Conference 2011, Glasgow, Scotland.

Sundmaeker, H., C. Verdouw, S. Wolfert, and L. P. Freire. 2016. "Internet of Food and Farm 2020." In *Digitising the Industry-Internet of Things Connecting Physical, Digital and Virtual Worlds*, 129–151. Gistrup/Delft: River Publishers.

Tadejko, P. 2015. "Application of Internet of Things in Logistics–Current Challenges." *Economics and Management* 7 (4): 54–64.

Tajima, M. 2007. "Strategic Value of RFID in Supply Chain Management." *Journal of Purchasing and Supply Management* 13 (4): 261–273.

Tao, F., Z. Ying, L. D. Xu, and L. Zhang. 2014. "IoT-Based Intelligent Perception and Access of Manufacturing Resource toward Cloud Manufacturing." *IEEE Transactions on Industrial Informatics* 10 (2): 1547–1557.

Theorin, A., K. Bengtsson, J. Provost, M. Lieder, C. Johnsson, T. Lundholm, and B. Lennartson. 2015. "An Event-Driven Manufacturing Information System Architecture." *IFAC-PapersOnLine* 48 (3): 547–554.

Thierry, M., M. Salomon, J. V. Nunen, and L. V. Wassenhove. 1995. "Strategic Issues in Product Recovery Management." *California Management Review* 37 (2): 114–136.

Thiesse, F., and T. Buckel. 2015. "A Comparison of RFID-Based Shelf Replenishment Policies in Retail Stores under Suboptimal Read Rates." *International Journal of Production Economics* 159: 126–136.

Thoben, K. D., S. Wiesner, and T. Wuest. 2017. "'Industrie 4.0' and Smart Manufacturing – A Review of Research Issues and Application Examples." *International Journal of Automation Technology* 11 (1): 4–16.

Thürer, M., Y. H. Pan, T. Qu, H. Luo, C. D. Li, and G. Q. Huang. 2016. "Internet of Things (IoT) Driven Kanban System for Reverse Logistics: Solid Waste Collection." *Journal of Intelligent Manufacturing* 1–10. doi:10.1007/s10845-016-1278-y.

Trab, S., E. Bajic, A. Zouinkhi, M. N. Abdelkrim, H. Chekir, and R. Hadj-Ltaief. 2015. "Product Allocation Planning with Safety Compatibility Constraints in IoT-Based Warehouse." *Procedia Computer Science* 73: 290–297.

Tranfield, D., D. Denyer, and P. Smart. 2003. "Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review." *British Journal of Management* 14 (3): 207–222.

Vachon, S., and R. D. Klassen. 2008. "Environmental Management and Manufacturing Performance: The Role of Collaboration in the Supply Chain." *International Journal of Production Economics* 111 (2): 299–315.

Vachon, S., and Z. Mao. 2008. "Linking Supply Chain Strength to Sustainable Development: A Country-Level Analysis." *Journal of Cleaner Production* 16 (15): 1552–1560.

Van der Vorst, J. G. A. J., O. Kooten, and P. A. Luning. 2011. "Towards a Diagnostic Instrument to Identify Improvement Opportunities for Quality Controlled Logistics in Agrifood Supply Chain Networks." *International Journal on Food System Dynamics* 2 (1): 94–105.

Velandia, D. M. S., N. Kaur, W. G. Whittow, P. P. Conway, and A. A. West. 2016. "Towards Industrial Internet of Things: Crankshaft Monitoring, Traceability and Tracking Using RFID." *Robotics and Computer-Integrated Manufacturing* 41: 66–77.

Verdouw, C. N., A. J. M. Beulens, and J. G. A. J. van der Vorst. 2013. "Virtualisation of Floricultural Supply Chains: A Review from an Internet of Things Perspective." *Computers and Electronics in Agriculture* 99: 160–175.

Verdouw, C. N., J. Wolfert, A. J. M. Beulens, and A. Rialland. 2016. "Virtualization of Food Supply Chains with the Internet of Things." *Journal of Food Engineering* 176: 128–136.

Veza, I., M. Mladineo, and N. Gjeldum. 2015. "Managing Innovative Production Network of Smart Factories." *IFAC-PapersOnLine* 48 (3): 555–560.

Vlachos, I. P. 2014. "A Hierarchical Model of the Impact of RFID Practices on Retail Supply Chain Performance." *Expert Systems with Applications* 41 (1): 5–15.

Wamba, S. F. 2012. "Achieving Supply Chain Integration Using RFID Technology." *Business Process Management Journal* 18 (1): 58–81.

Wang, T., Y. F. Zhang, and D. X. Zang. 2016. "Real-Time Visibility and Traceability Framework for Discrete Manufacturing Shopfloor." In *Proceedings of the 22nd International Conference on Industrial Engineering and Engineering Management 2015*, Singapore, 763–772.

Wang, J., and H. Yue. 2017. "Food Safety Pre-Warning System Based on Data Mining for a Sustainable Food Supply Chain." *Food Control* 73: 223–229.

Weyer, S., M. Schmitt, M. Ohmer, and D. Gorecky. 2015. "Towards Industry 4.0 – Standardization as the Crucial Challenge for Highly Modular, Multi-Vendor Production Systems." *IFAC-PapersOnLine* 48 (3): 579–584.

Whitmore, A., A. Agarwal, and L. D. Xu. 2015. "The Internet of Things-a Survey of Topics and Trends." *Information Systems Frontiers* 17 (2): 261–274.

Wollschlaeger, M., T. Sauter, and J. Jasperneite. 2017. "The Future of Industrial Communication: Automation Networks in the Era of the Internet of Things and Industry 4.0." *IEEE Industrial Electronics Magazine* 11 (1): 17–27.

World Economic Forum (WEF) Deloitte Touche Tohmatsu (Firm). 2012. *The Future of Manufacturing: Opportunities to Drive Economic Growth*. Geneva: World Economic Forum.

Xing, B., W. J. Gao, K. Battle, F. V. Nelwamondo, and T. Marwala. 2011. "E-RL: The Internet of Things Supported Reverse Logistics for Remanufacture-to-Order." Proceedings of the Fifth International Conference on Advanced Engineering Computing and Applications in Sciences, Lisbon, Portugal.

Xu, L. D. 2011. "Information Architecture for Supply Chain Quality Management." *International Journal of Production Research* 49 (1): 183–198.

Xu, R., L. Yang, and S. H. Yang. 2013. "Architecture Design of Internet of Things in Logistics Management for Emergency Response." 2013 IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing, Beijing, China.

Xu, L. D., W. He, and S. Li. 2014. "Internet of Things in Industries: A Survey." *IEEE Transactions on Industrial Informatics* 10 (4): 2233–2243.

Yamato, Y., K. Hiroki, and Y. Fukumoto. 2016. "Proposal of Lambda Architecture Adoption for Real Time Predictive Maintenance." 2016 Fourth International Symposium on Computing and Networking (CANDAR), Hiroshima, Japan.

Yan, J., S. Xin, Q. Liu, W. Xu, L. Yang, L. Fan, B. Chen, and Q. Wang. 2014. "Intelligent Supply Chain Integration and Management Based on Cloud of Things." *International Journal of Distributed Sensor Networks* 10 (3): 624839.

Yan, B., C. Yan, C. Ke, and X. Tan. 2016. "Information Sharing in Supply Chain of Agricultural Products Based on the Internet of Things." *Industrial Management & Data Systems* 116 (7): 1397–1416.

Yao, J. 2017. "Optimisation of One-Stop Delivery Scheduling in Online Shopping Based on the Physical Internet." *International Journal of Production Research* 55 (2): 358–376.

Yu, J., N. Subramanian, K. Ning, and D. Edwards. 2015. "Product Delivery Service Provider Selection and Customer Satisfaction in the Era of Internet of Things: A Chinese E-Retailers' Perspective." *International Journal of Production Economics* 159: 104–116.

Yuvaraj, S. and M. Sangeetha. 2016. "Smart Supply Chain Management Using Internet of Things (IoT) and Low Power Wireless Communication Systems." 2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), Chennai, India.

Zawadzki, P., and K. Żywicki. 2016. "Smart Product Design and Production Control for Effective Mass Customization in the Industry 4.0 Concept." *Management and Production Engineering Review* 7 (3): 105–112.

Zelbst, P. J., K. W. Green, V. E. Sower, and P. M. Reyes. 2012. "Impact of RFID on Manufacturing Effectiveness and Efficiency." *International Journal of Operations & Production Management* 32 (3): 329–350.

Zhang, Y., W. Wang, S. Liu, and G. Xie. 2014. "Real-Time Shop-Floor Production Performance Analysis Method for the Internet of Manufacturing Things." *Advances in Mechanical Engineering* 6: 270749.

Zhang, Y., W. Wang, N. Wu, and C. Qian. 2016. "IoT-Enabled Real-Time Production Performance Analysis and Exception Diagnosis Model." *IEEE Transactions on Automation Science and Engineering* 13 (3): 1318–1332.

Zhiduan, X. 2005. "Research on the Flexibility in Logistic Systems." *Chinese Journal of Management* 4: 441–445.

Zhong, R. Y., C. Xu, C. Chen, and G. Q. Huang. 2015. "Big Data Analytics for Physical Internet-Based Intelligent Manufacturing Shop Floors." *International Journal of Production Research* 55 (9): 2610–2621.

Zhong, R. Y., Y. Peng, F. Xue, J. Fang, W. Zou, H. Luo, S. T. Ng, W. Lu, G. Q. P. Shen, and G. Q. Huang. 2017. "Prefabricated Construction Enabled by the Internet-of-Things." *Automation in Construction* 76: 59–70.

Zhou, K., T. Liu, and L. Zhou. 2015. "Industry 4.0: Towards Future Industrial Opportunities and Challenges." In *Proceedings of 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, Zhangjiajie, China, 2147–2152.

Zhu, Q., and J. Sarkis. 2004. "Relationships between Operational Practices and Performance among Early Adopters of Green Supply Chain Management Practices in Chinese Manufacturing Enterprises." *Journal of Operations Management* 22 (3): 265–289.

Zhu, X., S. K. Mukhopadhyay, and H. Kurata. 2012. "A Review of RFID Technology and Its Managerial Applications in Different Industries." *Journal of Engineering and Technology Management* 29 (1): 152–167.