How the Internet of Things Technology affects the Supply Chain Management

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Abstract

The purpose of this study is to identify and analyze how the Internet of Things Technology (IoT) affects the Supply Chain Management (SCM) performance.
Through a systematic literature review, many applications were identified in the Operations field, which were grouped and analyzed according toan SCM framework.
It is concluded that the huge increase of information generated by IoT adoption leads either to incremental improvements in the SCM processes or radical improvements, with the emergence of new business models. The latter can facilitate the servitization of manufacturing companies, such as Business Ecosystems, which are Supply Networks with connected stakeholders.

Keywords: Internet of Things, Supply Chain Management, Business Ecosystems.

Introduction

Among recent technological advances, the IoT technology has been gaining prominent attention. Although the concept had been presented for the first time in 1999 by the MIT Auto-ID Center, by Ashton (2009), only more recently, the development and convergence of many technologies, such as the increase of miniaturization, power processing and the possibility of broad wireless connection, enabled the creation of new products, which connect to the internet and to sensors that detect physical changes around them, start to offer new functionalities, better reliability, better occupancy rate and greater operational capabilities, transcending the frontiers of traditional products.

We are therefore facing a new technology, with high transformation potential impact in economy and society. According to Mishra et al (2016), in their bibliometric study about applications and challenges of IoT, there is a limited number of studies about the relationship between the Internet of Things and supply chain performance. In order to fill this gap, this research tries to answer the following research question: *How can the applications in the operations field using IoT affect the Supply Chain (SC) performance*?

In order to answer this question, a systematic literature review was conducted that allowed the identification of many academic articles, published between 1999 and 2017, which focus on IoT applications with emphasis in Operations field.

This study concluded that IoT can lead to incremental improvements in SCM through the huge increase of Information Flow that causes direct impact in all SCM processes, or radical improvements in SCM, with the emergence of new business models that facilitate the servitization of manufacturing companies, such as the birth of the called Business Ecosystem, which consists of Supply networks with connected stakeholders.

The article is organized in the following manner: first, the IoT and SCM concepts are presented, followed by the systematic literature Review methodology. Next, the main finding of this review are systematized and analyzed, in view of possible impacts in the SCM regarding new SCM models and new business models. Lastly, the conclusion is presented, with suggestions of future research.

Internet of Things

- **Concepts**

According Ashton (2009), the word IoT was cited by the very first time by him, one of the MIT Auto-ID Center founders, during a presentation at Procter&Gamble (P&G) company, in 1999, when talking about Radio-frequency tags (RFID). However, it was only in 2005, when the International Telecommunication Union (ITU -2005) published the first report on this subject did the word "Internet of Things" become official and start to be used by researchers, companies and users. As stated by the report, "a new dimension was created in the information technology and communication world: at any time, from anywhere, we will have connectivity to anything. The connections will multiply and create a new dynamic network – the Internet of Things."

In addition, according to Atzori et al (2010), the main concept is that day-to-day objects can be equipped with processors capable of identification, sensitivity, networking and processing, allowing them to communicate with each other, with other devices and services, over the internet to achieve a purpose of use.

Miorandi et al (2012) states that the three main systemic characteristics of IoT are: everything communicates (wireless communication skills enable the creation of networks of interconnected objects/objects), everything is identified (connected things / objects can receive a unique identification) and everything interacts (it is possible to feel and interact with the environment when this capacity is present).

Another definition comes from the Cluster of European Research Projects on the Internet of Things (IERC - 2018), which states "A 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."

- **Applications**

Borgia (2014) proposes that applications using IoT can be grouped into three major domains: Industrial, Smart City, and Health and Welfare. The Industrial Domain encompasses industrial activities, involving commercial and financial transactions between companies or organizations, such as Logistics, Manufacturing, Process Monitoring, Banking, Government and Intermediary Sector, and Agriculture. The Smart City Domain consists of the possibility of applying the IoT to help in environmental sustainability, with an emphasis on efficient energy management and intelligent solutions for the daily lives of people. The Health and Welfare Domain refers to the development of intelligent services for the improvement of health activities, as well as for Society.

In a similar way, Mishra et al (2016) categorized IoT applications in four major domains: while the domains "Industry Domain" and "Healthcare domain" are basically identical to Borgia's categorization, "Smart environment domain" is directly linked to applications that can enhance the quality of life of people in several ways, like vehicles and parking communication that allow the automatization of the payment process, and "Personal and Social domain" is associated to applications generated by the combining sensors and smart devices, like home systems that enable residents to control activities via web applications.

Supply Chain Management

The need to increase quality and productivity, reduce working capital and lead-times delivery, and improve the level of service for customers, forced companies to seek opportunities for improvement and integration beyond their borders. As proposed by Lambert and Cooper (2000), competition was noticed to occur not only in the corporate environment, but in the scope of Supply Chains versus Supply Chains where each of the companies is inserted. Lambert et al. (1998) proposes the following definition of Supply Chain: "Supply Chain Management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders."

Cooper et al (1997) propose a framework for the study of SCM, whose participants range from raw material manufacturers through the various stages of production to the final consumer. This model is divided into three elements: Structure, Processes and Components. The processes run through the departments within the company, and also across corporate boundaries, which are: Customer Relationship Management (CRM), Customer Service Management (CSM), Demand Management, Order Fulfillment, Manufacturing Flow Management, Procurement, Product Development and Commercialization and Returns Management.

Methodology – Systematic Literature Review

A Systematic Literature Review was conducted between 1999 and September 2017 using Transfield et al (2003) methodology. First, a protocol was created (table 1), where all the rules for the search and selection of the articles were established.

Table 1 – Protocol for the Systematic Literature Review

Step	Details
Study identification strategy	Constructs identification (Internet of Things and Supply Chain Management)
	Key words identification: (Internet of Things, IoT) and (Supply Chain, Value Chain, Logistics, Operations)
	Code identification: (Internet of Things OR IoT) AND (Supply Chain OR Value Chain OR Logistics OR Operations).
	Search in 302 data bases (EBSCO, STOR, Emerald, etc.)
	Search from 1999 to Sept/2017
Study selection	Selection: Titles and Abstracts reading
	Selection: article full reading, looking for the capacity of answering the research question.
Data extraction and process monitoring	Selection: quality analysis considering Charvet el al (2008) article and impact factor greater than 1,278
	Analysis of contents of selected articles
Data Analysis and synthesis	Content analysis based on literature review by crossing data from different concepts, discussion and authors
	Answer the research question from what is known in the literature
	Synthesis of main contributions

The following keywords were used in the title and abstract search: (Internet of Things OR IoT) AND (Supply Chain OR Value Chain OR Logistics OR Operations). Then, a search was conducted in 302 databases, including EBSCO, JTOR and Emerald, and limited to just academic articles and written in English language.

A total of 881 articles were identified, and the related titles and abstracts were carefully read. The growing number of studies associated with this subject since 1999 are illustrated in Figure 1. Later, those with relation with the subject of research were selected (225 articles).

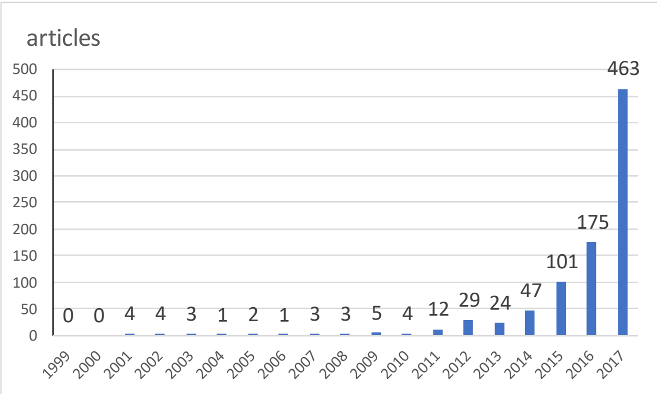

Figure 1 – Articles identified by year of publication

These 225 selected articles were entirely read, and, those with strong relation with the subject of research were selected (147 articles). Then, these articles were assessed in terms of quality.

First, in this step all the relevant journals identified in the Charvet et al (2008) article were selected. Since the work of Charvet was published in 2008, several periodicals with papers present at the selected base were noticed not to exist at the time or not to have an adequate academic maturity at that time, and in order to ensure that the research was not impaired in quality and comprehensiveness, an additional selection criterion was identified, the Impact Factor of each periodical. This was done using the following rule: we first identified the Impact Factor of each of the journals selected in the Quality Assessment step. The Impact Factor of the selected journals (1,278) was used as the cut-off factor, and it was decided to include all the articles present in periodicals with Impact Factor greater than or equal to 1,278 in the analysis for the next step. As a result of this Quality Assessment phase, a total of 59 articles were selected.

Finally, the final stage is the presentation of the findings and subsequent analysis in order to answer the research question based on the selected articles

Analysis of the Findings

- **Applications in Operations**

Based on the selected literature, an analysis was carried out in view of applications in the Operations field with potential impact on SCM performance. The result of this search was grouped into five Applications: Production Planning and Control, Warehousing Management Systems (WMS), New Business Models/Ecosystems, Products Tracking and Trace, Reverse Logistics/Closed Loop Supply Chain. Table 2 shows the number of contributions identified for each application.

Analysis according with Supply Chain Management model

To analyze how the IoT applications impact the performance of SCM, it was decided to use the SCM framework proposed by Cooper et al (1997) as a reference. These will be discussed and analyzed under the Information Flow component and each process of the framework:

Table 2 – Main applications of the IoT in the Operations field

	Production Planning and Control (PPS)	Warehousing Management (WMS)	New Business Models/Business Ecosystems	Products Tracking and Trace	Reverse Logistics /Closed loop supply chain
Number of solutions identified	21	12	8	24	4

- **Information Flow** – One of the major difficulties in the SCM is related to the lack of information over the various tiers. According to Ng et al. (2015), the suppliers located in the SC have little visibility of the actual consumption of the clients, since this information ends up being distorted along the chain, with only the information of the posterior tier being obtained, and so on. There are also difficulties in accurately identifying in real time the location and condition of the product until delivery to the customer. Also, once delivered, the specific information of its operation is also not available.

When analyzing the applications identified (table 2) it is noticed that the main functionality that IoT brings is a remarkable increase in the quantity and accuracy of product information throughout the SC. This information is now made available on a real-time online basis to all members of the SC in all tiers, simultaneously, eliminating asymmetry of information and its consequences, allowing the tracking and tracing of products, and obtaining information on their operation in clients, which greatly increases the possibilities for coordination, collaboration and integration among all SC members.

In the manufacturing process of the companies, this is also achieved, as seen in the applications in PPS and WMS, where it becomes possible to improve inventory management, and the production planning process, with increased flexibility, reliability and costs reduction.

• **Customer Relationship Management (CRM**) and **Customer Service Management (SRM)** - The particular information of the needs of the customers is captured and transmitted to the manufacturing companies, who know the details of the operation of each customer, enabling an increase in the level of customization. Besides, the information regarding products working is also made available, which facilitates the supporting service. According to the proposal of Ng et al (2015), with the use of the concept of Platform Strategy, in which the product is finished by the customer, according to its peculiarities, it reaches an extremely high level of customization. In this concept, the value is co-created by the customer in its use, since the customer brings new elements as diverse knowledge and features to maximize their use.

• **Demand Management** - Demand information from the consumer becomes more accurate, and permeates throughout the chain, allowing the reduction of inventories of products. Distortions from information asymmetry, which according to Forrester (1961), generate the Bullwhip effect, are minimized, further impacting inventory reduction.

• **Order Fullfilment** - Increasing the level of fulfillment of orders, through the best performance in identifying the products in the warehouse process, and tracking in the process of transportation to the customers, enables immediate corrective actions in order to guarantee the best customer service.

Several IoT applications have been identified in this sense, especially those related to perishable products, and the cold chain in particular, since it is characterized by the perishable nature of the products, the unforeseen variations in the lots of supplies and requirements of (Wang et al., 2004, Wang and Yue (2017, Yan et al. (2016), Luo et al (2016)).

To this end, Verdouw et al (2013,2015,2016) introduce the concept of supply chain virtualization, understood as a virtual representation of the real world, which allows the simulation and optimization of processes through software instead of physical inspections. With the use of the Internet, virtualization can be used dynamically in the operational management of the entire chain, so that supply chains can be monitored, controlled, planned and optimized remotely, online and in real-time, without the need of physical observations. In this manner, it is possible to plan, orchestrate and monitor the physical elements and resources of a Supply Chain, even though it is located in a place physically distant from the elements. In the specific case of perishable products, it is possible to carry out the reallocation of products, depending on the remaining shelf life, and through simulations of the available options, take proactive actions, such as change in the final destination of a batch of products to a location and maximize earnings. In addition, according to Bogataj et al (2017), it is possible to perform simulations to optimize Net Present value (NPV).

The information on the operation of the equipment allows the performance of predictive maintenance, reducing impacts not foreseen in the production schedule. Thus, Upasani et al (2017) propose a distributed algorithm that performs intelligent maintenance planning for machines in a job-shop manufacturing scenario.

• **Manufacturing Flow Management** – According with Babiceanu & Seker (2016), the IoT will connect physical devices such as sensors, actuators, RFID tags and readers, GPS units, and high-definition cameras, which will bring a series of benefits like increase of visibility of the manufacturing operations, improved efficiencies, workflow automation, optimized energy consumption, improved preventative maintenance, and real-time information exchange among manufacturing facilities. Upasani et al (2017) states the combination of sensors and computing infrastructure is becoming increasingly pervasive on the industry shop-floor, enabling the automation of many industrial practices, and the need of replacement of conventional planning techniques for those that may better use the capabilities of Cyber-Physical Systems (CPS) and Industrial Internet of Things (IIoT).

For Hofmann & Rüsch (2017), the IoT enables the concepts of CPS and Internet of Services (IoS), which are core components of called Industry 4.0, and its concept of “smart factory”. In the smart factory, characterized by decentralized production system, products find their way independently through production processes and are easily identifiable and locatable at any time, pursuing the idea of a cost-efficient, yet in a highly flexible and individualized mass production system.

According to Zhong et al (2016), Cloud Manufacturing is an upgraded advanced manufacturing model by the support of cloud computing, IoT, service-oriented technology, and Big Data-enabled decision mechanisms.

Tao & Meng (2017), similarly to Verdouw, propose the concept of virtualization called Digital Twin Shop-Floor (DTS), which consists in the converge of the physical and virtual worlds of the shop floor, enabling optimization and forecasting actions.

The widespread use of IoT in manufacturing allows the creation of a great amount of real-time and manufacturing data and logistics data that can be used to perform production-logistics collaboration, in order to achieve a flexible production system. To achieve this aim, Luo et al (2017) propose a Synchronized Production and Logistics, which is defined as synchronizing the processing, moving and storing of raw material, Work in Process inventory and finished product within one manufacturing unit by information sharing and joint scheduling to achieve synergic decision, execution and overall performance improvement. This concept is shared by various authors, such as Zhong et al (2016), Guo et al (2017), and Qu et al (2016).

.• **Supplier Relationship Management** – No specific applications have been identified in relation to this process, but a similar dynamic can be understood as CRM, which facilitates the entire process of hiring and evaluating suppliers from more accurate information obtained automatically.

• **Product Development and Commercialization** – In order to offer customized/personalized products Yang et al (2017) propose a connection model of product design and manufacturing in the IoT-enabled cloud manufacturing environment. In this model, social networks are used to connect consumers, manufacturers and third parties, and IoT allows the integration of cyber space, physical space and cloud manufacturing, so as to offer information sharing, interaction and sharing problem solving.

• **Return Management** – The possibility of products having sensors that monitor their performance and always inform when an abnormality occurs facilitates the entire process of maintenance and collection. Thus, according to Fang (2016), all product life cycle management is made easier, and it enables proposing a system for production optimization for decision making (buying, manufacturing, retrieving or final product disposal).

New Supply Chain Models and New Business Models

For several authors, the advent of IoT technology not only changes the SCM performance level, but also allows for the reconfiguration of SCM in different manners, leading to the possibility of new business models.

A possible example is the ability to facilitate the process of Servitization of companies, understood, according to Vandermerwe and Rada (1988), as the strategies of aggregation of value through the offer of combined packages of Products and Services.

According to Rymaszewskaa et al (2017), the development of the IoT offers a unique opportunity for companies to gain knowledge about how customers are using their products, allowing organizations to be able to achieve closer and better proximity to their customers and enabling reshape of their value chains by expanding the scope of their product–service offerings. An IoT-based servitization strategy is presented, implemented by three companies that through IoT functionalities such as production/operations data captured from equipment, machine-level sensor data and connecting transformer to intranet access, enabled reduction in manufacturing costs, reduction of costs of risks of outage/penalty and increase of product life cycle. A conceptual framework is also presented, aiming to contribute to digital servitization, with the particular focus on the potential of IoT-based solutions.

For Ng et al (2015) the use of IoT enables a modification of the business model from a dominant product logic (G-D Logic) to a dominant service logic (S-D Logic). The study concludes that the greater the need for customization, the more profitable the strategy of Platform Strategy becomes: Supply Chain ceases to be linear, to become a network, web or ecosystem.

According to Rong et al (2015), the IoT was intended as the connected network between things, but with the emergence of IoT technologies, there is an increase in businesses that can be involved, creating a business-ecosystem perspective instead of just a supply network. The IoT-based business ecosystem is not just a supply network with connected items but an extended supply network connecting all stakeholders. These stakeholders are players that can be connected with the IoT and can interact in a dynamic way and add value to the evolution of the business ecosystem. Both manufacturing and service delivery are enhanced by knowledge sharing, tools and solutions allowing for mutual learning and co-creation. So, the authors propose a framework for understanding Business Ecosystems based on the 6C (Context, Cooperation, Construct, Configuration, Capability and Change), in which the IoT permits the communication of many businesses in order to build such ecosystem.

Ryan and Watson (2017) state that IoT networks have many characteristics, such as connectivity, self-organization, emergence, co-evolution and adaptive behavior, which are generally regarded as a CAS (Complex Adaptive System). The CAS theory was pioneered by Holland (1995), to describe systems with many components that interact and self-adapt independently. The authors state that IoT networks will need to be self-organizing systems, which evolve into ordered systems from interactions among components, so that they can continue to operate as planned. IoT devices must monitor their environment so that when a failure occurs, they are able to establish connection to neighboring devices and cooperate, establish communication paths, in order to recover from local faults to restore normal operations.

Conclusion

The present work sought, through the use of systematic literature review methodology in the Operations field, to identify and analyze the impacts that IoT may have on SCM.

The IoT enables the creation of smart products, characterized by embedded sensors that connected with systems and equipment, increase the quality and quantity of information, on a real time basis. Such features allow for the development of many applications, such as WMS, products tracking and trace, generating increasing in order fulfilment, Manufacturing customization, lower inventory costs and increase of products and service quality.

These findings are in general in accordance with those of Haddud et al (2017) about benefits and challenges associated with the IoT integration in supply chains, which states that are many benefits both to individual organizations and to entire supply chain, with a highlight to increase in flexibility in production system, effective information sharing with supply chain members and focus on core strengths.

However, these improvements can be considered as incremental, since several authors suggest that there are possibilities for radical improvements, through new models of SCM and new business models that can facilitate the movement of Servitization of manufacturing companies. According to them, the IoT enables the transformation of the concept of Supply Chain into other forms of organization, called Business Ecosystem, in which different stakeholders may share knowledge, information, tools, in a way that permit to add value and allow for the co-creation of solutions that enhance manufacturing and services, in a dynamic, re-configurable and self-organized manners. The huge amount of data generated by IoT products require the intense use of other tools such as Big Data and Analytics, in order to fully accomplish the potential of value generation.

For these new Business Ecosystems, the current SCM frameworks seems to be no longer adequate, requiring the develop of new tools to provide a better understanding, like Social Networks, what offers new avenues of research in the Supply Chain field.

Besides, many authors in the Operations field state that a Supply Chain is a Supply Network and is in fact a CAS (Choi et al (2001), Surana et al (2005), Carter et al (2015)). The IoT network, if works according to the same CAS principles, may generate additional dynamism to Supply Networks, leveraging the business performance into a new level of performance, such as the increase in resilience capabilities through the self-organizing feature of CAS.

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