Examining potential benefits and challenges associated with the Internet of Things integration in supply chains

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Received 27 May 2017
Revised 11 July 2017
12 July 2017
24 August 2017
Accepted 24 August 2017

Abstract

Purpose – The Internet of Things (IoT) is expected to have a huge impact on businesses and, especially, the way we think about supply chain management (SCM). However, there is still a paucity of studies on the impact of IoT adoption on supply chains and on different aspects of the business in general. The purpose of this paper is to examine the perception of the academic community of the impact of the IoT adoption in organizational supply chains with a view to verify potential key benefits and challenges existent in the literature. The research presents the impact on an organization along with the impact across its entire supply chain.

Design/methodology/approach – Data were collected through the use of an online survey and 87 participants completed the survey. Participants were mainly from the academic community and were university scholars based in different countries located in six continents. Participants were authors, or co-authors, of academic papers published in the Decision Science Institute 2015 and 2016 annual conference proceedings, the 21st International Symposium of Sustainable Transport and Supply Chain Innovations, the *Supply Chain Management: An International Journal* 2016 issues, and the *Operations and Supply Chain Management: An International Journal* 2016 issues.

Findings – The authors were able to confirm the significance of some of the examined potential benefits to individual organizations and their entire supply chains. However, the study identified other potential benefits that were not seen as a direct impact of IoT adoption. Most of the examined potential benefits were found to contribute to a number of critical success factors for implementing successful SCM. The authors were also able to confirm that some of the examined potential challenges were still perceived as key hinders to IoT adoption but examined potential challenges were not seen as hurdles to IoT adoption.

Originality/value – To the best of the authors' knowledge, this is the first study of its kind. Although some literature attempted to provide an overview about the IoT management, no study has specifically explored potential benefits and challenges related to the adoption of IoT in supply chains and ranked them based on their significance. The results can be beneficial to academic scholars interested in the researched topic, business professionals, organizations within different sectors, and any other party interested in understanding more about the impact of adopting IoT on SCM.

Keywords Information technology, Adoption, Risks, Technology, Benefits, Information management, Challenges, Supply chain management, Internet of things (IoT), Value chain, Supply chains

Paper type Research paper

1. Introduction

The Internet of Things (IoT) as a term has been around for about 20 years and it first appeared in 1999. The term was coined in the context of supply chain management (SCM) by Kevin Ashton who was working on a research project at the Massachusetts Institute of Technology's AutoID lab to explore ways to improve business performance through linking the

Journal of Manufacturing Technology Management
Vol. 28 No. 8, 2017
pp. 1055-1085
© Emerald Publishing Limited
1741-038X
DOI 10.1108/JMTM-05-2017-0094

radio frequency identification (RFID) technology information to the internet (Gubbi *et al.*, 2013). There is no common definition for the IoT but it simply relates to the integration of physical objects communicating with one another and through the internet to achieve some useful objectives (Botta *et al.*, 2014; Whitmore *et al.*, 2015; Wortmann and Flüchter, 2015).

IoT facilitates a safe and trustworthy way of exchanging information related to goods and services in a global supply chain (Mishra *et al.*, 2016). IoT will be less a revolution than a valuable (and welcome) evolution that will contribute to the next wave of productivity gains driven by information technology transformation (Behrendt *et al.*, 2017). Kumar *et al.* (2015) identified 13 critical success factors, based on an extensive literature review of 66 journal articles, for successful implementation of SCM that include: top management commitment; development of effective SCM strategy; devoted resources for supply chain; logistics synchronization; use of modern technologies; information sharing with supply chain members; forecasting of demand on point-of-sale; trust development in supply chain partners; developing just-in-time capabilities; development of reliable suppliers; higher flexibility in production system; focus on core strengths; and long-term vision for survival and growth. Our study shows how these success factors are impacted by the adoption of IoT.

The IoT is believed to bring tangible business benefits (Borgia, 2014; Madakam *et al.*, 2015; Russo *et al.*, 2015). The adoption of the IoT has the potential to improve operational processes, reduce costs and risks due to its transparency, traceability, adaptability, scalability, and flexibility (Zhou *et al.*, 2015). However, the challenges facing the emergence of the IoT are numerous (technical and social) and these challenges must be overcome in order to ensure effective IoT adoption and diffusion (Whitmore *et al.*, 2015). Lee and Lee (2015) state that there is still a paucity of studies on the social, behavioral, economic, and managerial aspects of the IoT. This makes it very challenging for companies to make informed decisions as regards IoT adoption/implementation. Mishra *et al.* (2016) state that there are limited, if any, studies that look into the relationship between IoT adoption and the increase of organizational and supply chain performance. The same reference adds that the adoption process and the enablers, drivers, barriers, and models of IoT adoption by organizations and supply chain should be explored. Whitmore *et al.* (2015) conclude that IoT is not well represented in the management literature and it is dominated by research relating to IoT technologies.

The IoT has opened up a completely new set of opportunities for research and practice in SCM (Ng *et al.*, 2015). Mishra *et al.* (2016) proposed four future potential research themes two of which were directly related to IoT adoption in supply chains as follows: "What are the drivers and barriers of IoT implementation and adoption?"; "How can we explain IoT implementation and adoption using alternative organizational theories?"; "How can we measure the impacts of IoT on organizational and supply chain performance?"; and "Can we propose a holistic model that explains the acceptance of IoT applications?"

The purpose of this paper is to empirically examine the impact of IoT adoption on individual organizations and their entire supply chains. More specifically, the study attempts to answer the following two main research questions:

RQ1. What are the potential benefits to be gained when organizations and their entire supply chains adopt IoT?

RQ2. What are the possible challenges to be faced when organizations and their entire supply chains adopt IoT?

There are five sections in this paper. Section 1 introduces the topic, research motivation, and purpose of the research. Section 2 reviews relevant literature on IoT overview, digital supply chain (DSC), and IoT in supply chains. Section 3 describes the used research methodology, including instrument development, sample and data collection, participants profile, data analysis methods, and instrument reliability and validity testing. Section 4 presents data analysis and the study results. The final section discusses the conclusions, implications of the findings, and limitations and future research.

2. Literature review

2.1 Overview of the IoT

IoT can be understood as a combination of three main elements: web-based (middle-ware), things-based (e.g. sensors), and semantic-based (knowledge) (Chandrakanth *et al.*, 2014). Botta *et al.* (2014) defined IoT as intelligent and self-configuring nodes (things) interconnected in a dynamic and global network infrastructure. It represents one of the most disruptive technologies, enabling ubiquitous and pervasive computing scenarios. The IoT can also be defined as a network of hardware, software, devices, databases, objects, sensors, and systems, all working at the service of humanity (Wu *et al.*, 2016). A foundational technology for the IoT is the RFID technology, which allows microchips to transmit the identification information to a reader through wireless communication (Da Xu *et al.*, 2014). The IoT enables physical objects to see, hear, think, and perform jobs by having them to "talk" to each other, to share information and to coordinate decisions. These physical objects become smart by using underlying technologies such as ubiquitous and pervasive computing, embedded devices, communication technologies, sensor networks, internet protocols and applications (Al-Fuqaha *et al.*, 2015). Gartner identifies the top ten IoT technologies for 2017 and 2018 (Gartner Press Release, 2016). See Table I for details.

Technology	Description
IoT security	Security technologies will be required to protect IoT devices and platforms from both information attacks and physical tampering
IoT analytics	New analytic tools and algorithms are needed now, but as data volumes increase through 2021, the needs of the IoT may diverge further from traditional analytics
IoT device (thing) management	The IoT also brings new problems of scale to the management task. Tools must be capable of managing and monitoring thousands and perhaps even millions of devices
Short-range IoT networks	Low-power, short-range networks will dominate wireless IoT connectivity through 2025, far outnumbering connections using wide-area IoT networks
Wide-area networks	The long-term goal of a wide-area IoT network is to deliver data rates from hundreds of bits per second (bps) to tens of kilobits per second (kbps) with nationwide coverage, a battery life of up to 10 years, an endpoint hardware cost of around $5, and support for hundreds of thousands of devices connected to a base station or its equivalent
IoT processors	The processors and architectures used by IoT devices define many of their capabilities, such as whether they are capable of strong security and encryption, power consumption, whether they are sophisticated enough to support an operating system, updatable firmware, and embedded device management agents
IoT operating systems	A wide range of IoT-specific operating systems has been developed to suit many different hardware footprints and feature needs
Event stream processing	Distributed stream computing platforms (DSCPs) have emerged. They typically use parallel architectures to process very high-rate data streams to perform tasks such as real-time analytics and pattern identification
IoT platforms	IoT platforms bundle many of the infrastructure components of an IoT system into a single product: (1) low-level device control and operations; (2) IoT data acquisition, transformation, and management; and (3) IoT application development
IoT standards and ecosystems	Standards and their associated application programming interfaces (APIs) will be essential because IoT devices will need to interoperate and communicate, and many IoT business models will rely on sharing data between multiple devices and organizations

Source: Gartner Press Release (2016)

Table I. Top 10 IoT technologies for 2017 and 2018

The adoption of IoT continues to expand and it is expected to have an enormous impact on consumers, businesses, and society as a whole. The world-wide IoT solutions market is expected to grow from US$1.9 trillion in 2013 to US$7.1 trillion in 2020, and the number of installed base of IoT units is expected to grow to 28.1 billion in 2020 (Lund *et al.*, 2014). It is also predicted that more than half of major new business processes and systems will incorporate some elements of the IoT by 2020 (Gartner Inc., 2016). IoT adoption is expected to continue to grow in logistics (supply chains and warehousing), retailing, manufacturing, healthcare, energy and utilities, home appliances, heavy equipment, education, insurance, airlines, etc. (Gregory, 2015; Kambies *et al.*, 2016; Lee and Lee, 2015; Maksimović *et al.*, 2015; Natarajan *et al.*, 2016). Overall, IoT applications can be categorized into four major domains: industry domain; healthcare domain; smart environments domain; and personal and social domain (Mishra *et al.*, 2016). Table II presents IoT applications and their benefits to the previously identified sectors.

The adoption of IoT solutions can yield more transparency and visibility of information and materials flow within business processes. This is important for the accuracy and availability of real-time information and the operations transactions along forward and reverse movement of physical goods in both services and manufacturing industry (Kumar *et al.*, 2016; Reaidy *et al.*, 2014; Sun, 2012; Ting *et al.*, 2010; Xu *et al.*, 2012). Another key potential benefit businesses can obtain from implementing the IoT is the improvement in products tracking and traceability (Costa *et al.*, 2012; Cao *et al.*, 2013; Uddin and Al Sharif, 2016). Other potential benefits may include better inventory management and control (Fan *et al.*, 2015; Reaidy *et al.*, 2015; Thiesse and Buckel, 2015), improved integration levels of internal business processes (Mann, 2015), enabling a strategic redesign of all operations and business processes in an integrated fashion to allow better operational performance improvements (Ferretti and Schiavone, 2016), and improved operational efficiency as a whole (Li and Li, 2017). This study will examine

Table II.
IoT adoption benefits within several sectors

Sector	IoT applications/benefits
Logistics	Constructing a seamlessly integrated environment, enhancing the scalability, configurability, and extendibility of the production system, facilitating autonomous agent-based local collaboration, and promoting quick rescheduling and planning in production logistics (Yu and Wang, 2016)
Retailing	Automated checkouts, better inventory management, store layout optimization, customer tracking, item location identification, on-shelf availability, real-time in-store promotions, augmented reality, and smart customer service (Bok, 2016)
Manufacturing	Improved processes, self-optimization, autonomous decision making, decentralized supply chains, more connections of manufacturing processes, smart products, individualized distribution and procurement, and better monitoring and control of physical processes (Roblek *et al.*, 2016)
Healthcare	Clinical care, remote monitoring, and early intervention/prevention (Kulkarni and Sathe, 2014)
Energy and utilities	Streamlines information flow, heightened asset performance, mitigated supply chain risks, product quality and consistency, energy management, smart thermostat, etc. (Kyriazis *et al.*, 2013; Moreno *et al.*, 2014; SAP Corporation, 2014; Zheng and Carter, 2015)
Home appliances	Energy consumption management, interaction with appliances, detecting emergencies, home safety and finding things easily, home security, etc. (Khan *et al.*, 2012)
Heavy equipment	Assets monitoring, traceability, and tracking (Velandia *et al.*, 2016)
Education	New educations systems, more empowered (digital) students, new ways of instruction, etc. (Agrawal and Mazumdar, 2015; Selinger *et al.*, 2013)
Insurance	Establish direct, unmediated customer relationships, individualize offerings of products, features, and access options (Koenig *et al.*, 2016)
Airlines	Better luggage management, better booking services, improved passengers' navigation in airports, better airport parking management, etc. (Alghadeir and Al-Sakran, 2016)

35 potential benefits a business and its entire supply chain may gain from the adoption of IoT-related solutions. The significance of each benefit will be identified and overall ranking will be provided and discussed.

2.2 DSC

The DSC can be defined as the strategic and operative exchange of information (financial, production, design, research, and/or competition) between members of the chain to enhance communications (Korpela *et al.*, 2017). The DSC consists of eight key elements: integrated planning and execution, logistics visibility, procurement 4.0, smart warehousing, efficient spare parts management, autonomous and B2C logistics, prescriptive supply chain analytics, and DSC enablers (Schrauf and Berttram, 2016). DSCs enable business process automation, organizational flexibility, and digital management of corporate assets (Chase, 2016). The goal of the DSC is ambitious: to build an altogether new kind of supply network that is both resilient and responsive (Schrauf and Berttram, 2016). Meier (2016) identified eight digital technology trends in SCM (see Table III) and provided brief descriptions about what each one provides to the business.

The digital revolution has affected all aspects of business including supply chains (Chase, 2016). SCM, as a key business priority present within almost every manufacturing company's strategy, finds itself in the center of this upcoming digital era, where almost everything will be connected to almost everything via the internet (Farahani *et al.*, 2017). In a study on the rise of Industry 4.0 conducted by PwC, more than third of more than 2,000 respondents say that their companies have started to digitize their supply chains and 72 percent expect to have done so in five years (Schrauf and Berttram, 2016). The digitalization will become one of the major research topics for the SCM community in the future (Pflaum *et al.*, 2017). Recent developments concerning digitalization are expected to play an increasingly significant role in the management and design of global supply chains (Klötzer and Pflaum, 2017). Based on the review in this section, it is evident that understanding potential implications of digitizing supply chains is crucial. Our study explores the impact of IoT adoption on SCM, and this is one of the key aforementioned digital technology trends. A number of key potential benefits businesses, and their supply chains, would gain as a result of IoT implementation will be examined, and their importance will be categorized/ranked; thus, the study fulfills this research need/gap.

Digital technology trend	Functions
Mobility	Mobile applications for performing business processes at any time and any place
Big and smarter data	(Near) live analysis of large volumes of structured and non-structured data to get deeper insights and enable reliable decision making
Cloud computing	Internet-based IT infrastructure to enable collaborative processes and scalable total cost of ownership (TCO)
Social media	Private and business-oriented networks for communication and collaboration purposes to be leveraged as additional data sources and sinks
Predictive and prescriptive analytics	Analysis of structured and non-structured data and recognition of specific patterns (through usage of advanced algorithms) to enable more precise predictions of future behaviors
Internet of Things	Seamless integration of physical objects (e.g. machines with sensors, labor, etc.) into the information network to make use of high amount of additional data
3D printing and scanning	Mass customization of different types of products to most individual customer needs
Robotics	Machines with appropriate intelligence to perform specific processes faster, cheaper, safer, and better quality results

Source: Meier (2016, p. 235)

Table III. Digital technology trends in supply chain management

2.3 IoT and SCM

Supply chain integration is important in improving business performance. This can be achieved through reducing cost, improving responsiveness, increasing service level, and facilitating decision making. Information sharing and collaboration as well as the agility are the key characteristics of the supply chain integration (Yan, Xin, Liu, Xu, Yang, Fan, Chen, and Wang, 2014; Yan, Zhang, and Vasilakos, 2014). From an SCM perspective, the IoT may allow machine-enabled decision making with minimum or no human intervention. It deals with integrating and enabling information communication technologies including RFID, wireless sensor networks, machine-to-machine systems, mobile apps, etc. (Zhou *et al.*, 2015). The IoT use in supply chains could bring visibility to each individual item, generating a highly visible supply chain, where the location and characteristics of all the things in the supply chain could be ascertained at any point in time (Geerts and O'Leary, 2014). Within the supply chain, IoT usage leads to an increase in profits, a reduction in excess product that quickly loses value, faster response to changing client needs or supplier availability, and more optimization of shipments and the assurance of complete deliveries (Robinson, 2015). The supply chains that respond and adjust to this fast IoT growth will achieve greater benefits and more competitive advantages in the new business environment (Li and Li, 2017). The IoT adoption will make businesses act in a predictive manner instead of reacting to the challenges of a complex and volatile market. Reacting in a predictive manner will help organizations significantly improve their operational performance through an effective management of production levels. This will also lead to a more efficient delivery of services and products to the market easing the common constraints of unpredictable demand and supply disruptions.

Companies need to embrace such IoT solutions in a smart manner to incorporate these technologies that sustain more effective supply chains. Most companies fail due to poor integrations of technology in their supply chain (Majeed and Rupasinghe, 2017). There are many challenges and barriers that can be encountered when adopting the IoT. Some of these included in the literature are: businesses still do not comprehend the potential gains they may obtain from the adoption of IoT and this acts as the reason why many enterprises have not decided to embrace it yet (Da Xu *et al.*, 2014; Lee and Lee, 2015; Ryan and Watson, 2017). Challenges with obtaining the access to employees who possess the required knowledge and skills remain another key factor hindering the IoT adoption (Hung, 2016; Ryan and Watson, 2017). In addition, incorporating new technologies into existent business environments, structures, and models has always been a challenge. This also remains the case when the IoT is implemented (Dijkman *et al.*, 2015; Hognelid and Kalling, 2015; Pfisterer *et al.*, 2016). Other challenges may be linked with internal and external technological integration (Bröring *et al.*, 2017; Buntz, 2015; Da Xu *et al.*, 2014; Gnimpieba *et al.*, 2015; Hussain, 2016; Valmohammadi, 2016). Other barriers to the adoption of IoT are the risks and variabilities that may arise from such use of ecosystems (Lee and Lee, 2015; Reaidy *et al.*, 2015; Riggins and Wamba, 2015). Finally, many businesses simply are not ready for such a change. They lack the required architecture (objects, networks, data services, etc.) (Bi *et al.*, 2014; Bughin *et al.*, 2015; Jin *et al.*, 2014; Li *et al.*, 2015). Our research examines 30 potential challenges businesses, and their supply chains, may face when embracing the IoT.

Based on the review of literature on IoT, DSCs, and integration of IoT in supply chains, a conceptual model can be developed to portray the impact of IoT adoption on organizations and their supply chains (see Figure 1). Our study examines potential benefits and challenges associated with the IoT adoption within supply chains and the results would help organizations respond and adjust quicker to the IoT growth and achieve greater competitive advantages.

3. Research methodology

3.1 Instrument development

The primary data for this research were collected through the use of an online survey and these are based on perceptions from the academic community. To our best knowledge, there was no similar developed and used instrument by other studies in the past. Thus, the design of this survey was primarily based on information extracted from the available literature to form meaningful, and relevant, statements. The survey consisted of four main parts in addition to The General Information part. The General Information section consists of four main questions including: the participants' field and area of expertise; years of experience in their current field; their level of knowledge of the IoT; and their geographical location. The participants were asked to share their perception by rating their responses on a five-point level of agreement Likert scale to answer the statements included under the four main parts of the survey. Part 1 included 17 potential benefits individual organizations may gain when adopting the IoT. A total of 17 related statements were used in the survey as shown in Table VI. Part 2 included 18 possible benefits the entire supply chain network gain when IoT is adopted across the chain as shown in Table VII. Part 3 consisted of 15 potential risks individual organizations may face when adopting the IoT as presented in Table VIII. Part 4 consisted of 15 possible challenges and risks that the entire supply chain network may encounter when implementing the IoT as shown in Table IX.

3.2 Sample and data collection

The data for this research were collected during February and March 2017 through a web-based survey developed on the QuestionPro online platform. The authors identified two potential sources of primary data for this study: practitioners who have direct involvement with IoT implementation, and academics who specialize in areas related to this technology. Although it would be more useful to gain insights from practitioners, it was not possible to get access to a good sample size from this group who are located in different global areas to avoid the results been interpreted as biased. Thus, a decision has been made to target the second group.

The selected participants were either authors or co-authors of academic papers on three international conference proceedings and two international academic journals from operations and SCM discipline. The participation e-mail invitation was initially sent to 641 individuals who published or co-published articles in the Decision Science Institute 2015 and 2016 Annual Conference Proceedings and the 21st International Symposium of Sustainable Transport and Supply Chain Innovations. A second invitation was sent to 104 individuals who either published or co-published journal articles in 2016 issues of the *Supply Chain Management: An International Journal* and the *Operations and Supply Chain Management: An International Journal*. In total, e-mail invitations were sent to 745 participants, 239 viewed the survey, 124 started completing it, and 87 fully completed surveys were received resulting in a response rate of 11.67 percent. Out of the 87 fully completed surveys, 73 were from those who presented at the selected conferences and 14 from those who published at the two selected SCM journals. More specifically,

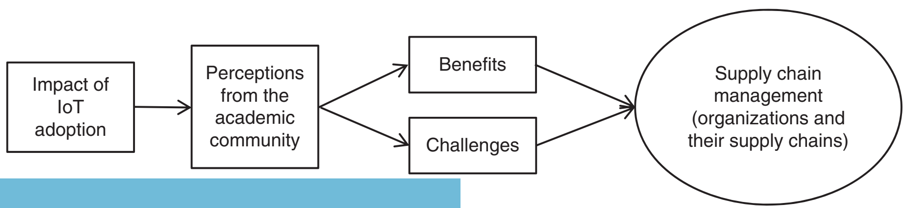

Figure 1.
Research framework

11.38 percent of the participants selected from the identified conferences completed the survey and 13.46 percent of the participants from the second group fully completed the survey. As it can be seen, the response rate was closely similar from the two targeted groups; thus, it was not possible to infer some observations about which of the two groups should yield better response rates should they be targeted in future studies.

3.3 Profile of participants

The profile of participants in this study is provided in Table IV. The participants' responses indicate that 39.08 percent had SCM expertise, 14.94 percent indicated their field as operations management, 11.49 percent stated business and management as their main area of expertise, 11.49 percent had a technology management background, and 22.98 percent indicated other areas of expertise, e.g. production management, service management, strategic management, and management of information systems. Table IV shows that 25.28 percent of the participants had 1-5 years of work experience in their current field, 21.83 percent had 6-10 years, 26.43 percent had 11-20, and a similar percent of 26.43 had 21 years or more. As regards the knowledge of the IoT, almost 60 percent of participants heard or read about the topic, 20.68 percent worked on projects or research involving IoT aspects, 12.64 percent teach IoT topics or modules, and only 0.06 percent stated that this was the first time to hear about the topic. With regard to where participants were physically located (see Figure 2), 41.37 percent were in North America (the USA), 32.18 percent in Asia, 16.9 percent in Europe, and 0.11 percent were based in South America, Africa, and Australia (see Figure 2 for more details).

3.4 Data analysis methods

The IBM Statistical Package for the Social Sciences (SPSS) version 21 was used to analyze the collected data in this study. First, the reliability and validity of the used data collection

Question	Frequency ($n = 87$)	Percentage
Field and main area of expertise		
Supply chain management	34	39.08
Operations management	13	14.94
Business and management	10	11.49
Technology management	10	11.49
Other	20	22.98
Years of experience in current field		
1-5	22	25.28
6-10	19	21.83
11-20	23	26.43
21+	23	26.43
Knowledge of the Internet of Things		
Worked on projects/research involving IoT aspects	18	20.68
Teach IoT topics/modules	11	12.64
Heard/read about the topic	52	59.77
This is the first time to learn about the topic	6	0.06
Geographical location		
North America	36	41.37
Asia	28	32.18
Europe	14	16.09
Africa	4	0.04
South America	4	0.04
Australia	3	0.03

Table IV.
Profile of participants

Figure 2. Participants' geographical location as displayed on QuestionPro

tool were examined. In order to examine the consistency and reliability of items in each of the four used main constructs in the used survey, Cronbach's *α* values and corrected item-total correlation coefficients were used. Also, an exploratory factor analysis was used for each of the used items within the four used constructs to examine their construct validity. Second, descriptive analyses were conducted to calculate frequency means for each item within the four constructs that used the five-point Likert level of agreement scale. The standard deviation was also calculated for each item.

3.5 Reliability and validity of research instrument

Reliability is defined as the proportion of variance in observed test score that is related to true scores (Cronbach, 1951; McDonald, 1999; Lo and Yeung, 2006) of the scale items in the same construct (DeVellis, 1991; Hinkin, 1995).

As mentioned earlier, Cronbach's *α* values and corrected item-total correlation coefficients were used to examine the consistency and reliability of the four used constructs. As shown in Table V, the Cronbach *α* coefficient value for the benefits to individual organizations construct was 0.935, for the benefits to entire supply chain construct it was 0.940, challenges to individual organizations had a coefficient value of 0.906, and challenges to the entire supply chain construct had a Cronbach *α* coefficient value of 0.947. Rivard and Huff (1988) suggest that Cronbach's values exceeding *α* coefficient of 0.7 thresholds provide reliability evidence for internal consistency of the measurement scales. Although an acceptable reliable coefficient is normally 0.7 or higher, lower thresholds are sometimes used in the literature (Santos, 1999). For new instruments, constructs with reliability values as low as 0.5 is also acceptable (O'Leary-Kelly and Vokurka, 1998). Although the used instrument in this study was new, the Cronbach *α* coefficient values for the four used constructs were all above 0.90. Because the closer to 1 the result is, the more reliable the

Construct	No. of items	Mean	SD range	Cronbach's *α*	Range of corrected item-total correlation
Benefits to individual organizations	17	4.11	0.708-0.834	0.935	0.528-0.732
Benefits to entire supply chain	18	3.92	0.671-0.990	0.940	0.469-0.772
Challenges to individual organizations	15	3.94	0.733-1.039	0.906	0.520-0.723
Challenges to entire supply chain	15	3.88	0.784-0.998	0.947	0.634-0.800

Table V. Summary of findings in Cronbach's *α* reliability test analysis construct becomes (Cohen *et al.*, 2003), it can be concluded that this new survey instrument be considered as an extremely reliable research tool. Tavakol and Dennick (2011, p. 1) explained that "a low value of alpha could be due to a low number of questions, poor inter-relatedness between items or heterogeneous constructs." In our used four survey constructs, we believe that the number of examined items under each construct are adequate and provide a thorough picture of the four examined themes. Also, each of the used items, within each construct, is directly related to the main theme of the construct and all of the used statements are inter-related. Thus, we relate the high Cronbach α coefficient values of the four used constructs to these two main factors.

The corrected item-total correlation values were also calculated for all the items within the four used constructs. For the first used construct as seen in Table VI, the item-total correlation values ranged from 0.528 to 0.732. In Table VII, the second used constructs, these correlation values ranged from 0.469 to 0.772. Table VIII shows that the item-total correlation values for this construct were between 0.520 and 0.741. Finally, the same correlation values for the fourth used construct, as shown in Table IX, ranged between 0.634 and 0.800. The literature suggests that these item-total correlation values should be at least 0.40 (Gliem and Gliem, 2003). Thus, the corrected item-total correlations for all of the included items within the four used structures were all above 0.40 which is encouraging, indicating good internal consistency for the used scale items, and that all the items relate to each other.

Table V also shows the participants' agreement levels with each of the four used main constructs. The benefits of individual organizations construct had the highest agreement level with a mean value of 4.11. Followed by the challenges to individual organizations construct (mean = 3.94), the benefits to entire supply chain construct had a mean value of 3.92, and the fourth construct of the challenges to entire supply chain had the least agreement levels with a mean value of 3.88.

Items	Mean	Item-total correlation	Factor loading	Rank
More transparency and visibility of information and material flows	4.39	0.528	0.576	1
Improved products tracking and traceability	4.34	0.611	0.581	2
Better control and management of inventories	4.29	0.710	0.680	3
Improved integration of internal business processes	4.18	0.683	0.764	4
Development of operational efficiency	4.17	0.662	0.788	5
Better support to e-commerce platforms through reliability and availability in information	4.17	0.537	0.495	6
Improved fleet and transportation management	4.16	0.732	0.610	7
Better predictive maintenance of assets	4.15	0.637	0.641	8
Production adjustments based on real-time information of the demand and capacity availability	4.15	0.638	0.766	9
Insights from customer patterns and behavior	4.14	0.688	0.643	10
Better proactive replenishment of material	4.09	0.694	0.602	11
Improvement in company assets utilization, reduction in machinery loss and downtimes	4.05	0.687	0.622	12
Production process optimization by detecting conflicts and inefficiencies	3.95	0.689	0.612	13
Prediction of optimal level of production by reducing overproduction and underproduction	3.94	0.649	0.691	14
Cost saving during production process in raw material, energy, water, human, machine, equipment	3.92	0.719	0.629	15
Procurement strategies optimization in product recovery operations, i.e. acquisition mgmt. for end-of-use products	3.91	0.589	0.572	16
Facilitate product development and commercialization	3.86	0.695	0.549	17

Table VI.
Participants' perception of IoT potential benefits to individual organizations

Items	Mean	Item-total correlation	Factor loading	Rank
Development of real-time SCM with reduction of data distortion and improvement of business intelligence	4.15	0.533	0.600	1
Develop the performance management of SCs by reducing delays in data colleting and assessing and acting	4.07	0.654	0.647	2
Better integration along inter-organizational business processes	4.06	0.685	0.625	3
Transparency from local and international logistics operations	4.06	0.704	0.693	4
Development of reliability, responsiveness, and agility through fast exchange of real-time information and facilitating process activities improvements	4.05	0.688	0.662	5
Enhancement the real-time visibility of demand and capacity fluctuations	4.01	0.647	0.679	6
Improvement in just-in-time manufacturing through better production scheduling	4.01	0.662	0.580	7
Improvement in the control and management of SC foot print to ensure regulation compliance.	3.97	0.660	0.549	8
Reduction of Bullwhip effect within SCs	3.95	0.469	0.765	9
Execution of simulations, optimizations, and data analytics processes to improve SC OP effectiveness	3.94	0.602	0.731	10
Reduction of inventory levels throughout SC nodes	3.87	0.701	0.557	11
A disruptive technology that will reshape models of SCM considering autonomous parts from a digitalized value chain with electronic network of activities	3.85	0.733	0.608	12
Optimization of joint procurement process to the acquisition of used products in remanufacturing operations	3.85	0.565	0.610	13
Emerging of innovative operational architectures with analytical approaches and collaborative win-win model	3.84	0.760	0.641	14
Decentralization of decisions-computing power and processing time can be redirected to critical areas along the SC network based on availability and reliability of real-time data	3.83	0.731	0.670	15
Improve management resolution by involving additional elements within SC operational processes	3.77	0.764	0.681	16
Reduction of transactional inter-enterprises reactions	3.76	0.772	0.687	17
Supply chains will start to act in a predictable manner instead of reacting to the market needs	3.63	0.760	0.677	18

Table VII. Participants' perception of IoT potential benefits to entire supply chain

Given the fact that the survey instrument used was developed for this study and it has not been used before, an exploratory factor analysis (Principal Component) was used to examine its construct validity. This analysis will help to determine how, and to what extent, each item within the four main used constructs is linked to their underlined factors (Chong *et al.*, 2009). Hair *et al.* (2006) state that the rule-of-thumb is that factor analysis values greater than 0.30 should be considered significant, values greater than 0.40 should be considered more important, and values that are 0.50 or greater should be considered very significant. As shown in Table VI, the benefits to individual organizations construct had factor loading values ranging from 0.495 to 0.788. As shown in Table VII, the benefits to entire supply chain construct generated factor loading values between 0.549 and 0.765. As shown in Table VIII, the challenges to individual organizations items factor loading values ranged between 0.431 and 0.812. Finally, as shown in Table IX, the challenges to entire supply chains construct had values between 0.462 and 0.694. In summary, out of a total 65 used items in the four constructs; only three items had factor loading values below 0.50 but they were greater than 0.40 and the remaining 62 items had factor loading values greater than 0.50. Also, it is important to note that when the entire survey instrument is run at the SPSS at once (65 items) for factor analysis, the loading values ranged from 0.644 to 0.847; thus, the construct validity of the used instrument in this study is very significant.

Table VIII.
Participants' perception of IoT potential challenges to individual organizations

Items	Mean	Item-total correlation	Factor loading	Rank
Device and network security risks and vulnerabilities	4.23	0.583	0.542	1
Lack of a clear comprehension about the IoT benefits	4.18	0.616	0.670	2
Challenges in obtaining the needed supporting staff with right skills and knowledge	4.16	0.723	0.745	3
Risks associated with implementation of new business model	4.06	0.592	0.431	4
Technical and technological integration	4.05	0.533	0.571	5
Integration with technologies and operations outside operational boundaries	4.01	0.741	0.759	6
Enterprise management, data management, and operational processes integration	4.00	0.627	0.515	7
Loss of privacy, trust, confidentiality, and availability risks	3.97	0.646	0.686	8
Employees' resistance to new technologies and practices	3.94	0.520	0.597	9
Seamless integration of business processes, information and communication technologies in cyberspace	3.87	0.564	0.513	10
Compatibility among sensors, networks, and applications from different technology and vendors	3.84	0.538	0.628	11
Avoidance of malicious and unintentional security incidents involving employees, contractors, and vendors	3.80	0.595	0.719	12
Availability of financial resources to support implementation and maintenance	3.79	0.549	0.627	13
Applications coding development	3.66	0.531	0.812	14
Displacement of human resources	3.54	0.615	0.747	15

Table IX.
Participants' perception of IoT potential challenges to entire supply chain

Items	Mean	Item-total correlation	Factor loading	Rank
Integration along multiples supply chains with heterogeneous technologies and data services	4.10	0.634	0.462	1
Global standard of IoT communication protocol for smart objects and systems	4.01	0.666	0.504	2
Effective layers of security to eliminate sources of vulnerabilities throughout the SC nodes and links	3.98	0.800	0.694	3
Common managerial comprehension about IoT along SC main stakeholders	3.97	0.738	0.607	4
Establishment of effective IoT architecture throughout SCs involving objects, network, data services, and applications layers	3.93	0.710	0.564	5
Services platforms of storage to accommodate large volume of data with high levels of security and reliability	3.90	0.778	0.660	6
Identification of the economic model that will define and capture the business value for the benefit of SCM	3.89	0.682	0.526	7
Platforms to manage and control huge volume of data, velocity of processing, validation, and diversity of information	3.89	0.660	0.501	8
Financial investments from all participants to design and deploy IoT technologies and solutions	3.86	0.712	0.569	9
Diversity of industries operational models from common SC participants	3.86	0.697	0.545	10
Effective integration and synchronization of data and cloud computing systems	3.86	0.775	0.659	11
Design of new SC business models to support the still unstructured firm-oriented ecosystems	3.84	0.699	0.551	12
Services and technological products still not mature	3.80	0.669	0.507	13
Solutions for communication and signal coverage to attend different modes of transport and products	3.77	0.776	0.662	14
Challenge with just-in-time manufacturing regarding dynamic production scheduling	3.67	0.770	0.653	15

4. Analysis and results

4.1 Benefits to individual organizations

The used construct to examine potential benefits of IoT adoption to individual organizations consists of 17 items (see Table VI for details about these used items). The participants were asked to rate these 17 items using a five-point Likert scale ranging from "1 = strongly disagree" to "5 = strongly agree." Results, as shown in Table VI, indicate that the top potential benefits an individual organization is likely to gain from the adoption of IoT, as perceived by the participants, were: more transparency and visibility of information and material flows (mean = 4.39). This result supports the theoretical benefits pointed on several studies regarding the importance of accuracy and availability of real-time information and the operations transactions along forward and reverse movement of physical goods in both services and manufacturing industry (Sun, 2012; Ting *et al.*, 2010; Xu *et al.*, 2012; Reaidy *et al.*, 2014; Kumar *et al.*, 2016). The second top-ranked benefit was the improvement in products tracking and traceability (mean = 4.34), a crucial element within services and manufacturing operations to achieve efficiency enhancements in productivity through synchronized flow of material and information (Costa *et al.*, 2012; Cao *et al.*, 2013; Uddin and Al Sharif, 2016). Better control and management of inventories benefit took the third position (mean = 4.29), which supports theoretical and empirical evidences of studies in this field to develop operational performance in replenishment processes and warehousing management through reduction of inefficiencies of inaccuracy in inventory data (Fan *et al.*, 2015; Reaidy *et al.*, 2015; Thiesse and Buckel, 2015). The fourth perceived potential benefit was the improved integration of internal business processes (mean = 4.18). Besides the optimization of internal production process (Mann, 2015), the use of IoT provides a competitive advantage to a business and enables a strategic redesign of all operations business processes in integrated fashion to enable operational performance improvements (Ferretti and Schiavone, 2016). The fifth benefit was identified as a developed operational efficiency (mean = 4.17). This is a potential benefit that will allow enterprises to actively participate in relevant business opportunities along several business dimensions such as distributions, procurement, and in production by shortening the distances between entities, optimizing inventory levels, and reducing costs based on effective and dynamic operational strategies (Li and Li, 2017).

Conversely, the least potential benefits were: facilitate product development and commercialization (mean = 3.86). Companies continue to develop products based on hardware improvements, away from customer involvement, and in a fragmented way. The IoT concept, on the other hand, focuses on the service design in an integrated model where customer involvement is a key to the creation of a new dimension of products and services. This supports the adoption of customer-focused Quality Function Deployment approach and is managed through a virtual model wherein new products with sensors demand continuous improvements based on real-time data collection (Westerbeek, 2016; Turunen, 2017). The success of adopting IoT to develop product commercialization still largely depends on the industry to address residual challenges related to standardization and commercialization of sensors and microelectromechanical systems (Grace *et al.*, 2015). Procurement strategies optimization in product recovery operations, i.e. acquisition management for end-of-use products was perceived as the second lowest potential benefit (mean = 3.91). Although product recovery is a relevant topic under research in production management field (Fan *et al.*, 2015), this result supports the current state of the use of smart objects information in product lifecycle management where the use of IoT with product data technologies and STEP, the ISO 10303 standard to describe product information throughout its lifecycle, still lacks exploration (Kiritsis, 2011). Cost saving during production process in raw material, energy, water, human, machine, and equipment was perceived as the third least potential benefit (mean = 3.92). Several industries have already achieved some cost-reduction benefits as a result of adopting IoT but such adoption is not embraced by enterprises in a large scale (Kerravala, 2017; Schimek, 2017; Tracy, 2017). Intel and Fujitsu (Intel, 2017) revealed operational efficiencies and cost savings in manufacturing processes as two key benefits from the IoT adoption. Furthermore, the prediction of optimal level of production by reducing overproduction and underproduction (mean = 3.94) was perceived as the fourth least expected potential benefit. Several leaders from discrete manufacturing industry, e.g. Siemens, General Electric, Cisco, and Harley-Davidson gained benefits from implementing smart production with intelligent and automated decisions in their manufacturing plants through the use of IoT. This has enabled them to improve profitability, identify improvement opportunities, and effectively resolve business problems (O'Marah, 2015). On the other hand, production process optimization by detecting conflicts and inefficiencies was perceived as the lowest potential benefit (mean = 3.95). Kang *et al.* (2016) and Zhou *et al.* (2017) highlight that IoT technologies facilitates the global optimization of conventional production process in manufacturing environments, e.g. production, transportation, storage, equipment, information, services, and decision-making processes, through dynamic synchronization of multi-stage production system. Ghashghaee (2016) stated that Volvo car manufacturer adopted the IoT technology in one of its large automotive assembly plants and the key benefits from such implementation was the "production process optimization." Although this perceived potential benefit was rated relatively low, the significance level of this benefit was strongly defended by researchers, specialists, and practitioners.

In summary, the low-rated potential benefits IoT may provide to an organization are supported by several factors and challenges confirmed by the IoT institute. This includes: operations lacking defined workflows, doubts about obtaining the expected benefits, interconnection difficulties with existing legacy ICT systems, high costs of infrastructure installation and related services, lack of required knowledge and skills, and concerns with data sharing and security (Buntz, 2015).

4.2 Benefits to entire supply chains

The used construct to examine potential benefits of IoT adoption to entire supply chains consists of 18 items (see Table VII for details about these used items). Results, as shown in Table VII, indicate that the top potential benefits entire supply chains are likely to obtain from the adoption of IoT, as perceived by the participants, were: development of real-time SCM with reduction of data distortion and improvement of business intelligence that have shown to exert the strongest potential benefit from IoT adoption (mean = 4.15). We were able to confirm the importance of this benefit in line with previous works (e.g. Atzori *et al.*, 2010; Uckelmann *et al.*, 2011; Xu, 2011; Bi *et al.*, 2014; Bughin *et al.*, 2015; Dweekat *et al.*, 2017). Second, SCs performance management improvement by reducing delays in data collection, assessment, and decision-making was perceived as the second strongest potential benefit SCs would gain from adopting IoT (mean = 4.07). This finding matches what other studies have emphasized as the crucial role IoT plays in enhancing performance of SCs; however, there were no ratings for this potential benefit in these studies (e.g. Biswas and Sen, 2016; Dweekat and Park, 2016; Dweekat *et al.*, 2017). A third potential benefit that proved important is the better integration of inter-organizational business processes (mean = 4.06). However, our study concluded this potential benefit in the third place but other studies (e.g. Da Xu *et al.*, 2014; Ferretti and Schiavone, 2016; Macaulay *et al.*, 2015) highlighted this benefit as more significant. This is perhaps due to the fact that the adoption of IoT has moved to a more advanced stage where enterprises are seeking to achieve more strategic-oriented benefits, e.g. enhancing the overall SCs operational performance in alignment with new business strategic models wherein decisions are taken based on reliable and real-time data to the creation of innovative portfolio of products and services (Chan, 2015;

Gerpott and May, 2016; He and Da Xu, 2014; Lee, 2016; Li and Li, 2017; Wagenaar, 2012; Zhong *et al.*, 2016) and as it has been highlighted as the first and second top potentials benefits in this study. A fourth potential benefit that was ranked as significant was the transparency from local and international logistics operations (mean = 4.06). We were able to confirm the significance of this potential benefit and this goes in line with prior research works (e.g. Lee and Lee, 2015; Reaidy *et al.*, 2015; Wieland *et al.*, 2016). The fifth most perceived potential benefit SCs would gain from adopting IoT was the development of reliability, responsiveness, and agility through fast exchange of real-time information and facilitating process activities improvements (mean = 4.05). The confirmation of the significance of these benefits goes in line with those highlighted in previous research works (e.g. Bi *et al.*, 2014; Dweekat *et al.*, 2017; Reaidy *et al.*, 2015).

Conversely, while some of the examined benefits were ranked high, other potential theoretical benefits could not be strongly supported and the impact of IoT adoption on these changes was perceived less significant. The first least perceived benefits was that supply chains will start to act in a predictable manner instead of reacting to the market needs (mean = 3.63). This finding seems to contradict with outcomes of other research works (e.g. Michaelides, 2016; Lee and Lee, 2015; Tao *et al.*, 2014; Pang *et al.*, 2015) where predictions of, e.g. demand, risk, shelf-life, future outcomes, etc., have been seen as significant benefits IoT adoption can bring to SCM. The second least perceived potential benefit was the reduction of transactional inter-enterprises reactions (mean = 3.76). The influence of IoT adoption on reduction of transactional inter-enterprises reactions could not be strongly supported. Perhaps this was because it was unclear how such an impact may occur in practice or due to the still existing major barrier on having all SC entities actively participating as network nodes of an IoT ecosystem that interoperate through a homogeneous architecture of information model (Bröring *et al.*, 2017). The third least supported potential benefit was the improvement of management resolution by involving additional elements within SC operational processes (mean = 3.77). While prior studies explained that IoT adoptions support decision-making processes (e.g. Bi *et al.*, 2014; Da Xu *et al.*, 2014; Reaidy *et al.*, 2015), this study suggests that IoT adoption does not significantly impact management resolution processes. Perhaps IoT adoption is still immature due the significant costs related to technological and geographical coverage limitations in extending the sensing environment infrastructure throughout the whole supply chain. Thus, this prevents top management from utilizing the full potentials of increased operations visibility promoted by higher-resolution of data gathered from dynamic mapping of physical and virtual space to achieve business excellence (Fleisch, 2010; Fleisch *et al.*, 2014; Vermesan *et al.*, 2011).

The fourth least perceived potential benefit was the optimization of joint procurement process to the acquisition of used products in remanufacturing operations (mean = 3.85). Although prior works (e.g. Fang *et al.*, 2015; Ondemir and Gupta, 2014) strongly suggested that the IoT adoption significantly optimizes procurement, production and product recovery, and acquisition, recent research reveals that enterprises and procurement practitioners across Europe, the UK, and North America are still not strategically adopting IoT as a catalyst for deployment of innovative procurement solutions (Avery, 2015). The fifth least supported potential benefit was IoT as a disruptive technology that will reshape models of SCM considering autonomous parts from a digitalized value chain with electronic network of activities (mean = 3.85). Mixed responses have been collected about this potential benefit. A conceivable explanation about this may be found in the fact that IoT is seen by some as a revolution that will reshape entire supply chains but it is seen by others as an enabling technology that will contribute to the digitization of SCs in addition to other enabling technologies that will together and gradually reshape existing models of SCM (Lightwell, 2014). Therefore, revealing the difficulty of establishing an effective model of governance to a structured ecosystem and the logic regarding how the value will be created, delivered, and captured to all supply chains stakeholders (Chan, 2015; Fleisch *et al.*, 2014).

4.3 Challenges to individual organizations

The used construct to examined potential challenges an organization may face when implementing IoT has 15 items (see Table VIII for details about these used items).

Results, as shown in Table VIII, indicate that the top potential challenges an individual organization is likely to face when adopting IoT, as perceived by the participants, were: lack of a clear comprehension about the IoT benefits (mean = 4.18) that were perceived as the top challenge to IoT adoption. Although hundreds of papers have been published covering technological and technical challenges related to IoT technologies, the multi-applications and multi-technologies from IoT are still in the early development stages (Ryan and Watson, 2017). Therefore, a clear understanding regarding the long capital cycle and holistic comprehension of full potential business benefits achieved from the use of IoT are still major challenges to most of enterprises and practitioners (Da Xu *et al.*, 2014; Lee and Lee, 2015; Ryan and Watson, 2017). In the second place, challenges with obtaining the needed supporting staff with the right skill sets and knowledge (mean = 4.16) was seen as another key challenge. Ryan and Watson (2017) highlight that effectiveness in designing and deploying IoT solutions requires a set of knowledge across several technical and non-technical disciplines. This was also supported by other researchers (e.g. Hung, 2016). Risks associated with implementation of new business model (mean = 4.06) was rated as the third top potential challenge. The incentive of adopting IoT is linked with potential financial returns through the generation of new economic opportunities. Enterprises must clearly understand how value will be created, delivered, and captured considering financial return as a key in IoT. Also, they should evaluate the differences between business models from others applications and IoT application where combination of services and products are delivered through smart products within dynamic, wider, and complex environments (Dijkman *et al.*, 2015; Hognelid and Kalling, 2015; Pfisterer *et al.*, 2016).

Furthermore, the technical and technological integration challenges (mean = 4.05) was seen as the fourth top challenge to the IoT implementation. The difficulties with establishing interoperability and seamless integration between different technologies and network systems to create cyber-physical infrastructure of IoT ecosystems are seen by several researchers as key barriers associated with the adoption of IoT solutions (Da Xu *et al.*, 2014; Buntz, 2015; Hussain, 2016; Valmohammadi, 2016). Finally, the fifth perceived top potential challenge was the integration with technologies and operations outside operational boundaries (mean = 4.01). Although IoT applications and solutions are recognized as very important across industries, the challenges related to internal and external integration of vertical, heterogeneous, and closed systems remain major concerns to enterprises (Bröring *et al.*, 2017; Gnimpieba *et al.*, 2015; Hussain, 2016; Valmohammadi, 2016).

On the other hand, the least perceived potential challenges were: displacement of human resources (mean = 3.54). Although this potential challenge was ranked low, several economic research works advocate that the adoption of IoT will create relevant challenges at social and organizational levels regarding rearrangement of skilled and unnecessary manpower (Cottong, 2016; O'Halloran and Kvochko, 2015; Ryan and Watson, 2017). Thus, it is important to explore ways to involve the existent human resources instead of displace or replace them (Iansiti and Lakhani, 2014). The applications coding development (mean = 3.66) was perceived as the second perceived least challenge. According to several recent studies, a challenge that many organizations will need to face when adopting IoT solutions will be the talent shift of the required professional skills from software programmers to content analysis and value creation through data analytics for optimization and prediction applications (Rymaszewska *et al.*, 2017). The third perceived least challenge was the availability of financial resources to implement and maintain (mean = 3.79). The implementation of IoT solutions requires sensors and physical layer connectivity elements. It also requires data storage, data processing, data mining, and data security. In addition, it requires skilled professionals to develop, and continuous support, different necessary applications. On the other hand, the investment in innovative technologies such as IoT always carries a significant risk of financial loss and irreversibility of investments to organizations (Ericsson, 2015; Lee and Lee, 2015). Therefore, the limited number of IoT adoption case studies showing clear return-on-investment gains across industries creates a considerable barrier for single enterprises to embraces such disruptive innovative technology.

The fourth least perceived challenge was the avoidance of malicious and unintentional security incidents involving employees, contractors, and vendors (mean = 3.80). Security risks related to verification, authorization, privacy, access to the system, applications, network, and data remain one of the main challenges for organizations when managing IoT ecosystems (Alaba *et al.*, 2017). Thus, the human element is still considered as a constant risk of security incidents due the lack of managerial and maintenance care about access control within enterprises' ICT networks (Patel *et al.*, 2017). Therefore, the low ranking of this challenge does not reflect a comprehensive reality of current research trends in IoT security issues for organizations. Finally, the compatibility among sensors, networks, and applications from different technology and vendors (mean = 3.84) as the fifth least challenge an organization may face when adopting IoT. The interoperability among non-standard protocols and sensors is a real challenge for inter companies integration. Different technologies along distributed and heterogeneous organizational IoT environments must be seamlessly integrated. Also, the design and development of IoT solutions within enterprise boundaries, i.e. in an isolated ecosystem, allows the achievement of a much better degree of compatibility, integration, and interoperability among smart objects, wireless sensor network, communication protocol, cloud computing, and applications (Alaba *et al.*, 2017; Da Xu *et al.*, 2014; Ghashghaee, 2016; Hussain, 2016).

Although not recognized at individual enterprises level, the displacement of human resources will be a key consequence that many organization will face when embracing disruptive technologies such as IoT that will merge embedded system technology with smart industrial production process. Also, the level of data security, integrity, and avoidance of intentional behavior to the access of confidential information are certainly major concerns within certain sectors such as governmental and military; however, these were not perceived as very significant challenge by the participants in this study.

4.4 Challenges to entire supply chains

This construct was used to examine potential risks and challenges the entire supply chain would face when the IoT is adopted across the network and these include 15 potential challenges (see Table IX for details about these used items). Results, as shown in Table IX, indicate that the top potential challenges entire supply chains are likely to face when IoT is adopted, as perceived by the participants, were: integration along multiples supply chains with heterogeneous technologies and data services (mean = 4.10). We confirmed that integrating IoT technologies with existent used operational, analytics, and strategic systems/technologies within SCs is the most perceived challenge to adopting IoT successfully. This challenge was identified as one of the top difficulties by other researchers, too (e.g. Bi *et al.*, 2014; Bughin *et al.*, 2015; Riggins and Wamba, 2015). The second perceived top IoT adoption challenge was developing global standard of IoT communication protocol for smart objects and systems (mean = 4.01). This is a common challenge with new technologies adoption and this confirms similar concerns highlighted in some prior works (e.g. Fang *et al.*, 2016; Tan and Koo, 2014; Tao *et al.*, 2014; Riggins and Wamba; 2015). The third supported key challenge to IoT adoption is creating effective layers of security to eliminate sources of vulnerabilities throughout the SC nodes and links (mean = 3.98). This risk remains an issue that needs to be addressed when IoT is adopted. IoT devices are likely to be vulnerable to security risks due to lack of transport encryption, insecure web interfaces, inadequate software protection, and insufficient authorization. Although we were able to confirm that such risks are still important for IoT adoption, this potential challenge came third. Prior research works have considered security variability as the key challenge among other challenges (e.g. Lee and Lee, 2015; Reaidy *et al.*, 2015; Riggins and Wamba, 2015).

The fourth perceived challenge associated with IoT adoption was common managerial comprehension about IoT along SC main stakeholders (mean = 3.97). Although this theoretical challenge remains legitimate to several scholars, its degree of authenticity should be explored and validated along professionals of the SCM discipline and OEMs. It seems that knowledge about IoT is still limited to professionals and academics in general. For example, 115 participants viewed the used survey in our study but did not start completing it. Also, 124 started completing the survey but dropped before fully completing it. One possible reason behind this could be the lack of knowledge participants have about the survey topic. The fifth top supported potential challenge to IoT adoption was the establishment of effective IoT architecture throughout SCs involving objects, network, data services, and applications layers (mean = 3.93). We confirmed that such a challenge remains significant for a successful IoT adoption. This goes in line with several prior works that discussed similar challenges (e.g. Bi *et al.*, 2014; Bughin *et al.*, 2015; Jin *et al.*, 2014; Li *et al.*, 2015).

While the least perceived potential challenges were, first, challenge with just-in-time manufacturing regarding dynamic production scheduling (mean = 3.67). We could not confirm that this challenge is significant to IoT adoption. A conceivable justification for this may be found in the fact that IoT has already been widely used for planning and scheduling purposes and such a challenge will diminish as organizations adopt the IoT more. Such benefit was presented on some prior publications (e.g. Bi *et al.*, 2014; Reaidy *et al.*, 2015; Yan and Yan, 2017). The second least challenge to IoT adoption was solutions for communication and signal coverage to attend different modes of transport and products (mean = 3.77). This challenge was not seen as a major issue to IoT adoption. This could be attributed to technological advancements in certain applications that continue to introduce better solutions at more affordable prices which will lead to wider IoT implementations (Bughin *et al.*, 2015; Riggins and Wamba, 2015). However, another reason why some participants still saw this challenge as an issue could mainly be related to lack of signal coverage in certain physical manufacturing premises or on transportation fleet on the roads (Fang *et al.*, 2016; Yan, Xin, Liu, Xu, Yang, Fan, Chen, and Wang, 2014; Yan, Zhang, and Vasilakos, 2014).

The third least supported challenge was services and technological products still not mature (mean = 3.80). We confirmed that IoT products and services are no longer in the infancy stage. More and more IoT-related technologies, devices, software, etc., are introduced and organizations are progressively starting adopting more applications. This is an interesting finding that sends a message about expanding of IoT adoption in general. This supports a number of prior works discussions about IoT adoption (e.g. Bughin *et al.*, 2015; Lee and Lee, 2015; Yan and Yan, 2017). The fourth least supported challenge was design of new SC business models to support the still unstructured firm-oriented ecosystems (mean = 3.84). We confirmed that IoT adoption will impact the current traditional SCs business models. This implies that IoT adoption will gradually change the way of doing things which will ultimately lead to designing, and adopting, new business models. However, such a change will require time and transitioning efforts and perhaps that is why this challenge was ranked relatively low. This line of thoughts goes in line with other prior works (e.g. Bughin *et al.*, 2015; Jin *et al.*, 2014; Tao *et al.*, 2014).

It is also important to highlight that when results from the two used groups (Conferences and Journals) have been compared, the mean values of 55 out of 65 examined benefits and risks were higher for the Journals Group and Table X shows the top items that had the biggest differences. One possible reason for such differences in the reported perceptions of the two groups could be related to their level of knowledge about the IoT in general. For example, scholars who frequently attend and present at professional conferences tend to have more updated knowledge about new trends and their impacts. Thus, the perception of this group would normally differ from those who have strong theoretical knowledge purely based on what is published in the literature. Furthermore, this research examined benefits and risks that are already in the literature and this perhaps explains why participants from the Journals Group had higher level of agreement with the examined statements. As it is discussed in Part 05, it would be interesting to gain the perceptions of other groups, particularly industry professionals, and compare them to the results of this research.

5. Conclusions

5.1 Conclusions and recommendations

This study used a reliable and valid research instrument that included 65 scale items. These items were divided into four constructs, namely, IoT adoption benefits to individual organizations (17 items), IoT adoption benefits to entire supply chain (18 items), IoT adoption challenges/risks to an individual organization (15 items), and IoT adoption challenges/risks to entire supply chain (15 items). In conclusion, the study demonstrated the following: the mean values for the examined 35 potential benefits, for an organization and its

		Items mean values		
Construct	Items	Journals' participants	Conferences' participants	Difference
Challenges to entire SC	Identification of the economic model that will define and capture the business value for the benefit of SCM	4.42	3.80	0.62
Challenges to an organization	Challenges in obtaining the needed supporting staff with right skills and knowledge	4.67	4.08	0.59
Challenges to entire SC	Solutions for communication and signal coverage to attend different modes of transport and products	4.25	3.69	0.56
Challenges to an organization	Loss of privacy, trust, confidentiality, and availability risks	4.42	3.89	0.52
Challenges to entire SC	Integration along multiples supply chains with heterogeneous technologies and data services	4.50	4.04	0.46
Challenges to entire SC	Diversity of industries operational models from common SC participants	4.25	3.80	0.45
Benefits to an organization	Production adjustments based on real-time information of the demand and capacity availability	4.50	4.09	0.41
Benefits to entire SC	Emerging of innovative operational architectures with analytical approaches and collaborative win-win model	4.17	3.79	0.38
Benefits to entire SC	Reduction of transactional inter-enterprises reactions	4.08	3.71	0.38
Benefits to entire SC	Enhancement the real-time visibility of demand and capacity fluctuations	4.33	3.96	0.37

Table X. Comparisons of results from the selected journals and conferences supply chain, were 3.63 and above on a five-point scale and had mode values of 4 and 5. These were equivalent to "Agree" and "Strongly Agree" on the used five-point agreement Likert scale. This indicated that IoT can provide valuable benefits and may result in achieving competitive advantages for individual organizations and their entire supply chains. On the other hand, the participants rated high the examined 30 potential challenges an individual organization and its supply chain are likely to face when adoption IoT. The mean values of the examined 30 items had 3.54 and above and mode values of 4 and 5. These were equivalent to "Agree" and "Strongly Agree" on the used five-point agreement Likert scale. This indicates that there are still a number of recognized challenges and risks that organizations need to overcome before adopting IoT and harvest potential benefits.

Table XI shows how the examined benefits in this study contribute to the 13 critical success factors for implementing SCM identified by (Kumar *et al.*, 2015). As shown in Table X, IoT adoption contributes to the different critical success factors as following: higher flexibly in production system (five contributors); effective information sharing with supply chain members (four contributors); focus on core strengths (four contributors); development of effective SCM strategies (three contributors); use of modern technologies (three contributors); devoted resources for supply chain (three contributors); forecasting of demand on point-of-sale (two contributors); development of reliable suppliers (two contributors); focus on core strengths (two contributors); and logistics synchronization (one contributor).

On the other hand, the examined 30 potential challenges associated with IoT adoption can be categorized into the groups. As show in Table XII, the majority of challenges and risks are associated with technical aspects of the IoT technology, e.g. installation and operational. The second category includes the organizational challenges. These are related to current business environments and the need to embrace the new way of doing things when IoT is adopted. The remaining challenges were related to available resources needed to acquire IoT-needed technologies. It is recommended that organizations assess their current organizational and technological environments and determine what should be done differently in order to be ready to adopt IoT. Overcoming any potential challenge or risks in advance is also strongly recommended.

It is important to mention that the significance/insignificance of the examined potential benefits and challenges have sometimes been confirmed with other studies' findings. However, these were different on several other occasions. We think that is because our data were collected from academics and some of the compared against studies used case studies and practitioners from the industry.

5.2 Research theoretical contribution

The contribution of this study lies in examining top benefits individual business and their entire supply chains can obtain from adopting IoT. The study has also examined top challenges individual organizations and entire supply chains may encounter when adopting IoT. The findings from this study can be considered a rich source of insights about IoT impact on SCM and what organizations should consider when implementing IoT solutions. This study provides starting points for the implementation of IoT in supply chains and it can also be used as a ground for future research endeavors that seeks to understand aspects related to business benefits from IoT adoption. Overall, the findings of this study fill some of the highlighted literature gap of related studies about IoT adoption and its potential (e.g. Borgia, 2014; Lee and Lee, 2015; Madakam *et al.*, 2015; Mishra *et al.*, 2016; Ng *et al.*, 2015; Russo *et al.*, 2015; Whitmore *et al.*, 2015; Zhou *et al.*, 2015).

5.3 Managerial implications

In addition to the discussed theoretical contributions, this study allows to draw conclusions relevant to IoT adoption for organizations and supply chains. Organizations remain hesitant

	Critical success factor	IoT adoption impact on the critical success factor
1	Top management commitment	N/A
2	Development of effective supply chain management strategy	Procurement strategies optimization in product recovery operations, i.e. acquisition mgmt. for end-of-use products Improve management resolution by involving additional elements within SC operational processes Supply chains will start to act in a predictable manner instead of reacting to the market needs
3	Devoted resources for supply chain	Improved fleet and transportation management Better proactive replenishment of material Reduction of inventory levels throughout SC nodes
4	Logistics synchronization	Transparency from local and international logistics operations
5	Use of modern technologies	A disruptive technology that will reshape models of SCM considering autonomous parts from a digitalized value chain with electronic network of activities Emerging of innovative operational architectures with analytical approaches and collaborative win-win model Better support to e-commerce platforms through reliability and availability in information
6	Information sharing with supply chain members	More transparency and visibility of information and material flows Better support to e-commerce platforms through reliability and availability in information Production adjustments based on real-time information of the demand and capacity availability Development of reliability, responsiveness and agility through fast exchange of real-time information and facilitating process activities improvements
7	Forecasting of demand on point-of-sale (POS)	Production adjustments based on real-time information of the demand and capacity availability Enhancement the real-time visibility of demand and capacity fluctuations
8	Trust development in supply chain partners	Improvement in the control and management of SC foot print to ensure regulation compliance
9	Developing just-in-time capabilities	Improvement in just-in-time manufacturing through better production scheduling
10	Development of reliable suppliers	Development of reliability, responsiveness and agility through fast exchange of real-time information and facilitating process activities improvements Decentralization of decisions-computing power and processing time can be redirected to critical areas along the SC network based on availability and reliability of real-time data
11	Higher flexibility in production system	Production adjustments based on real-time information of the demand and capacity availability Production process optimization by detecting conflicts and inefficiencies Prediction of optimal level of production by reducing overproduction and underproduction Cost saving during production process in raw material, energy, water, human, machine, equipment. Improvement in just-in-time manufacturing through better production scheduling
12	Focus on core strengths	Development of operational efficiency Improved products tracking and traceability Better control and management of inventories Improvement in company assets utilization, reduction in machinery loss and downtimes
13	Long-term vision for survival and growth	Cost saving during production process in raw material, energy, water, human, machine, and equipment

Table XI.
IoT adoption impact on key SCM critical success factors

Table XII. IoT adoption challenges and their sources

Challenge category	Challenge source
Technological challenges	Device and network security risks and vulnerabilities
	Technical and technological integration
	Integration with technologies and operations outside operational boundaries
	Compatibility among sensors, networks, and applications from different technology and vendors
	Applications coding development
	Integration along multiples supply chains with heterogeneous technologies and data services
	Global standard of IoT communication protocol for smart objects and systems
	Effective layers of security to eliminate sources of vulnerabilities throughout the SC nodes and links
	Establishment of effective IoT architecture throughout SCs involving objects, network, data services, and applications layers
	Services platforms of storage to accommodate large volume of data with high levels of security and reliability
	Platforms to manage and control huge volume of data, velocity of processing, validation, and diversity of information
	Effective integration and synchronization of data and cloud computing systems
	Solutions for communication and signal coverage to attend different modes of transport and products
Organizational challenges	Lack of a clear comprehension about the IoT benefits
	Risks associated with implementation of new business model
	Loss of privacy, trust, confidentiality, and availability risks
	Employees' resistance to new technologies and practices
	Seamless integration of business processes, information and communication technologies in cyberspace
	Avoidance of malicious and unintentional security incidents involving employees, contractors, and vendors
	Displacement of human resources
	Common managerial comprehension about IoT along SC main stakeholders
	Identification of the economic model that will define and capture the business value for the benefit of SCM
	Diversity of industries operational models from common SC participants
	Design of new SC business models to support the still unstructured firm-oriented ecosystems
	Challenge with just-in-time manufacturing regarding dynamic production scheduling
Resources availability challenges	Challenges with obtaining the needed supporting staff with right skills and knowledge
	Availability of financial resources to support implementation and maintenance
	Financial investments from all participants to design and deploy IoT technologies and solutions

about allocating the necessary resources to start embracing IoT projects. This low deployment of IoT solutions at a world-wide level is a result of doubts about gained benefits, uncertain financial, social, and technical dimensions associated with such deployment, and remains major obstacles to its wider acceptance and adoption by enterprises and supply chains participants. Therefore, this research attempted to generate valuable insights for IoT services and technology providers, professionals, and top management from both manufacturing and services industries. The findings from this study are particularly valuable for those businesses that are still waiting to embrace and deploy local initiatives regarding the use of innovative technologies of smart objects, cyber product systems, and data analytics from IoT solutions within their current operations.

Our study provides support to top management to better understand business implications related to IoT adoption. Managers can be equipped with more holistic understanding of potential challenges related to IoT adoption that businesses are likely to face, internally and within their entire supply chains. Such understanding will enable them to better comprehend the top elements and factors that should be considered and addressed in advance, within their initiatives, projects, and designs of IoT applications. Furthermore, this will lead to making better strategic decisions about acquiring the suitable technologies, resources, and external support required for the IoT adoption. This will result in implementing best practices to fulfill their quest to optimize operational performance through better level of business competitiveness from acquiring innovative technological solutions. Furthermore, this study suggests that more managerial attention is paid to not just the selection of IoT technology to be implemented but also to the potential techno-organizational implications of such adoption for organizations and supply chains. The role of top management in IoT adoption is particularly crucial in determining the level of such adoption and ensuring that required support, resources, and sponsorship are provided throughout the implementation phases. Our study can be a valuable source of relevant information for managers to develop, promote, and defend the acceptance of IoT projects prior to embarking on adoption journeys, during the implementation phases, and later during the operational stage, therefore promoting the leverage of current initiatives and success in the deployment of IoT solutions. As mentioned earlier, the authors believe that because the IoT technologies are still in the development process and their applications within different sectors are still expanding, the findings from our theoretical study based on academics views can be considered as a suitable guidance for practical implementations.

5.4 Limitations and future research

This research explored participants perceptions about a number of pre-determined potential benefits and challenges individual organizations and their entire supply chains are likely to encounter when adopting the IoT. Future research may explore benefits and challenges within organizations through the use of open-ended or multiple-choice survey questions. This may result in reporting different potential benefits and challenges that were not included in our study. Furthermore, this study examined potential benefits and challenges related to IoT adoption but it did not explore how best organizations should adopt IoT implementation within supply chains. Thus, further studies may look into this theme. Also, our study did not explore ways to overcome the examined challenges. In addition to exploring IoT adoption best practices, recommending how to overcome implementation hurdles would be another future research stream. Finally, this study was limited to individuals, mainly university scholars, who published academic papers in two professional international conferences and two relevant academic journals. The authors made this decision based on the assumption that the level of IoT implementation is still limited and it would be better to gather primary data from experts who have theoretical knowledge about the selected topic. Two of the selected venues were professional conferences and relevant scholarly journals. However, as time proceeds and perhaps more development of IoT solutions is embraced, we suggest that further research may consider capturing perceptions of participants from different industries. This will allow researchers to capture practical insights from practitioners and professionals who are likely to have direct involvement of IoT adoption and operation. Finally, every effort has been made to ensure that data are collected from a larger group but our study was based on the perceptions of 87 participants and it is strongly recommended that a larger sample is used.

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