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Optimization and control of new product development processes by the adoption of Internet of Things

FELIPE BASTOS DOS REIS
FACULDADE DE ECONOMIA, ADMINISTRAÇÃO E CONTABILIDADE DA UNIVERSIDADE DE SÃO PAULO - FEA

LEONARDO AUGUSTO DE VASCONCELOS GOMES
FACULDADE DE ECONOMIA, ADMINISTRAÇÃO E CONTABILIDADE DA UNIVERSIDADE DE SÃO PAULO - FEA

PAULO TROMBONI DE SOUZA NASCIMENTO
FACULDADE DE ECONOMIA, ADMINISTRAÇÃO E CONTABILIDADE DA UNIVERSIDADE DE SÃO PAULO - FEA

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Abstract

Real-time data collection by Internet of Things (IoT) can help companies optimize and control internal process more efficiently. Prior research analyzed benefits and potential applications associated with IoT adoption, although little empirical evidence exists on how this technology impact operations that are pursuing to optimize and control internal process in product development. The objective of this article is to discuss the adoption of IoT in new product development processes. A database of IoT case studies is used to discuss the operational impacts of the adoption of IoT in the optimization and control of internal processes in product development. The analysis of 54 selected case studies from the secondary database IoT One allow to clarify how companies are adopting this technology in new product development processes. This study identified that most of the analyzed case studies adopted the Internet of Things in the machinery and equipment sector using mature technology developed over 5 years ago, few companies have adopted recent and more innovative technological solutions. The use of this technology was more intense in the phase of developing the specifications and creating the new product. The commercialization phase was the second most impacted, especially due to the ability of this technology to promote improvements in manufacturing processes. The stage of discovering opportunities was the least impacted by the implementation of this technology. Many studies analyzed the impact of information and communication technologies adoption into new product development processes, but few articles address the use of IoT in these processes.

Keywords: Internet of things, new product development, technology adoption, NPD processes, optimization of internal processes,

1. INTRODUCTION

The Internet of Things (IoT) is a network of interconnected devices that has the ability to autonomously detect and transmit data to humans or other devices with the support of wireless sensor networks, data analytics and cloud computing (Ancarani, Di Mauro, Legenvre & Cardella, 2019; Gubbi, Buyya, Marusic & Palaniswami 2013). The communication of data in IoT is done through wireless technologies, the most important for the use of this technology are the wireless sensor networks and RFID (Xu, Xu & Li, 2018). The adoption of IoT is essential for the successful implementation of Industry 4.0 in companies (Frank, Dalenogare & Ayala, 2019)

This technology creates an ecosystem in which machines, products and systems can exchange information with each other in order to optimize and control internal processes in different functional areas in organizations (Fatorachian & Kazemi, 2018; Marques, Agostinho, Zacharewicz & Goncalves, 2017). IoT can assist in various departments of the company (e.g. marketing, R&D) because this technology allows to collect relevant data from different sources, analyze the information in a systematic way to generate knowledge for organizations and support strategic decision making (Taylor, Reilly & Wren, 2020). Companies can use IoT with different objectives, such as predictive maintenance of machines, optimization in the use of internal resources, increase in efficiency of quality control and in new product development processes (Ghobakhloo, 2018; Yerpude & Singhal, 2019).

In the process of developing new products, companies need to identify opportunities from different sources and select the best opportunities to create new products and services (Ulrich & Eppinger, 2012). The use of information and communication technologies in new product development (NPD) processes can assist in identify opportunities from different sources and increase the productivity and efficiency of these processes (Ibrahim & Obal, 2020; Nikabadi & Sepehrnia, 2019). These technologies can facilitate the development of successful products for the market and make NPD processes more effective (Barczak, Sultan & Hultink, 2007; Durmuşoğlu & Barczak, 2011; Mauerhoefer, Strese & Brettel, 2017). The Internet of Things is a technology that allows the constant communication of information by different stakeholders which can be located inside or outside the boundaries of the organization, in this manner IoT helps organizations to create important insights for the development of new products (Yerpude & Singhal, 2019).

Internet of Things "can provide a higher level of market intelligence to support new product design" (Taylor, Reilly & Wren, 2020, p. 150). The use of IoT in new product development processes can be considered a key activity related to the adoption of this technology by companies (Dijkman, Sprenkels, Peeters & Janssen, 2015). This technology collects, analyzes and integrates information from different sources and can create knowledge for companies in different departments (de Sousa Jabbour, Jabbour, Foropon & Godinho Filho; Fatorachian & Kazemi, 2018). IoT facilitates the creation of products aligned with consumer demands and the reduction of costs in the new product development processes (Yerpude & Singhal, 2019). The adoption of the IoT enables the collection and analysis of data in real time that allows the optimization and control of the NPD processes making them more effective (Yerpude & Singhal, 2018).

Real-time data collection by Internet of Things can help companies optimize and control internal process more efficiently. The study of IoT adoption to optimize and control internal processes is a recent topic in the academic context and "the consequences of adopting a radical technology into an NPD process and the factors which help or harm such adoptions is relatively less studied" (Ibrahim & Obal , 2019, p. 5). Cavalcante and Fettermann (2019) state that most academic papers on IoT focus on technical aspects of the technology and few studies address the management of processes related to the development of new products.

Prior research analyzed benefits and potential applications associated with IoT adoption, although little empirical evidence exists on how the adoption of this technology impact operations that are pursuing to optimize and control internal process in product development. The objective of this article is to discuss how companies use this technology in new product development processes. This study seeks to answer the following research questions:

RQ1: How companies are adopting IoT in new product development processes?

The study exploits secondary data to pursue the objective. An IoT projects database provided case studies to throw light into the operational impacts related with the adoption of this technology to control and optimize new product development processes. The cases studies offer a great opportunity to understand how companies are adopting IoT in NPD processes and how the use of this technology impacts the operation in this context. The cases provide information on applicable industries and functions, functional area that adopted the IoT, challenge, customer, solution applied, technology maturity and operational impacts. The selected cases studies were examined to discuss how companies are adopting this technology in new product development processes. The operational impacts of each case were investigated using a three-phased decomposition approach of NPD processes: discovery, development and commercialization of the new product (Durmuşoğlu & Barczak, 2011).

This article is structured as follows. First, the theoretical background provides an overview of IoT, new product development processes and the adoption of this technology in this context. Second, the methodology is presented followed by the cases studies analyses. The last topic contains the conclusion.

2. THEORETICAL BACKGROUND

2.1 Overview of IoT

The Internet of Things (IoT) is a network formed by machines, sensors, systems and interconnected products that collect and transmit data, enabling the tracking and monitoring of different types of devices that are integrated with this technology (de Sousa Jabbour et al., 2018; Fatorachian & Kazemi, 2018). This technology is supported by cloud computing that "can provide the virtual infrastructure for such utility computing which integrates monitoring devices, storage devices, analytics tools, visualization platforms and client delivery" (Gubbi et al., 2013, p. 1645). This network is considered essential for the implementation of Industry 4.0 since it permit the development of cyber-physical systems that are necessary for the use of various technologies in an integrated manner (Marques et al., 2017). IoT is a technology that works as a basis for the adoption of Industry 4.0 in organizations (Frank, Dalenogare & Ayala, 2019).

The devices, or "things", connected to the IoT must have a communication standard that allows the interoperability of the system, enabling the autonomous exchange of data between different types of equipment with intelligent interfaces (Xu, Xu & Li, 2018). Radio frequency tags (RFID) and wireless sensor networks (WSNs) are technologies that have helped the development of the Internet of Things, through them it is possible to transmit data based on the use of interconnected intelligent equipment capable of sensing and monitoring the environment (Xu, He & Li, 2014). IoT has become a more developed technology in recent years as wireless devices, such as radio frequency tags (RFID) and sensors, have evolved and become more sophisticated (Singh & Bhanot, 2016). Internet of Things is based on the idea that interconnected intelligent equipment exceeds the human capacity for data collection, processing and communication (Ghobakhloo, 2018).

The structure of the Internet of Things is presented by some authors through an architecture formed by multiple layers. The first layer is the sensing layer, in this level the "things" collect and transform data using sensors or other hardware; the second layer is the communication layer where the data is transferred between devices interconnected; the third layer is the software layer and it permit the storage and transformation of the data into value information or knowledge; the last layer is the application layer that provide services and interaction with users (Ancarani et al., 2019). The architecture formed by multiple layers exposes that this technology "integrates various devices equipped with sensing, identification, processing, communication, and networking capabilities" (Xu, He & Li, 2014, p. 2240).

This network has the capacity to optimize production processes, as it is able to analyze a vast amount of data that professionals would not be able to examine to identify opportunities for improvement in company productivity (Kiel, Müller, Arnold & Voigt, 2017). The devices connected to the Internet of Things, in addition to collecting data, has the ability to transmit information that will be analyzed and used to assist the decision-making process (Yerpude & Singhal, 2018). The collection and analysis of data in real time allows better control and planning of production processes, so this technology can also assist in the flexibility and

customization of the production line (Kiel et al., 2017; Moktadir, Ali, Kusi- Sarpong & Shaikh, 2018).

The data collected in real time facilitates communication between different departments of the company and stakeholders (e.g. marketing, R&D, consumer) and benefit the product development process in organizations (Yerpude & Singhal, 2018; Yerpude & Singhal, 2019). This technology can provide market information "without the usual costs associated with customer surveys and focus groups" (Taylor, Reilly & Wren, 2020, p.153)

Wireless communication, sensor networks and smartphones will continue to evolve, this will permit more networked things to connect the Internet of Things (Xu, He & Li, 2014). Companies will be able to use the information collected by this technology to make strategic marketing decisions more assertively (Taylor, Reilly & Wren, 2020). The technological advancement of the last few years makes it difficult to predict a future without the interaction between smart devices in order to generate benefits for humanity, so the IoT has enormous potential for application in different contexts in society (Singh & Bhanot, 2019).

2.2 New product development (NPD)

New products are generated through the identification of opportunities that will enable the development of new goods, in this context "an opportunity is a product description in embryonic form, a newly sensed need, a newly discovered technology, or a rough match between a need and a possible solution" (Ulrich & Eppinger, 2012, p. 34). The development of new products is important to maintain the organization's competitiveness in the long term and for a successful launch it is essential to capture and understand the demands of the market (Nikabadi & Sepehrnia, 2019; Yerpude & Singhal, 2019).

Companies that can develop a product aligned with consumer expectations and with agility can create a competitive advantage over competitors (Yerpude & Singhal, 2018). As opportunities are generated and identified, it is necessary to evaluate all of them to select the most valuable ones, which will be developed and tested to assess their viability for the organization (Ulrich & Eppinger, 2012). Firms that are able to identify opportunities from multiple sources can increase the possibility of generating quality knowledge that will create successful products for the market (Nikabadi & Sepehrnia, 2019; Ulrich & Eppinger, 2012). The creation and sharing of knowledge are fundamental processes for the development of new products (Nikabadi & Sepehrnia, 2019).

Firms create new goods through new product development processes, these processes assist organizations in the creation, development and commercialization of new items on the market (Durmuşoğlu & Barczak, 2011; Ulrich & Eppinger, 2012). The NPD process consists of several steps that will generate the new product, "including idea generation, concept design, implementation, product testing and manufacturing" (Ibrahim & Obal, 2020, p. 3).

Ulrich and Eppinger (2012) propose a generic process for the development of new products consisting of six phases: planning, concept development, system-level design, detail design, test and refinement, production ramp-up. Durmuşoğlu and Barczak (2011) examined the use of different information technologies across the NPD processes adopting a three-phased decomposition approach: discovery, development and commercialization of the new product. Table 1 presents the activities related to each of the three NPD processes.

Table 1 – Activities of NPD processes

NPD process	Activities
Discovery	Identify market opportunities, collect and analyze customer requirements, generate product or service ideas, test product concepts with customers, develop a clear description of the selected product requirements
Development	Translate the product requirements into a final design, test the product, create a concrete product ready for commercialization
Commercialization	Formulate, execute and synchronize the launch of the product, production ramp up, train the distribution and sales forces, purchase media time and space, develop media messages

Source: adapted from Durmuşoğlu and Barczak (2011)

New product development processes require efficient integration between multiple organization's activities to facilitate the exchange of knowledge (Nikabadi & Sepehrnia, 2019). In concept development, for example, it is necessary to analyze and integrate information on customer needs, on competitors' existing products, on the generation and selection of concepts for the new product, on the final specifications, on the concept tests and on the planning of subsequent activities on new product development process (Ulrich & Eppinger, 2012). New technologies can help professionals who develop new products in the process of integrating the wide variety of information collected by the organization, so the adoption of new information and communication technologies (ICT) can assist in increasing productivity and support in the phases of the NPD process (Ibrahim & Obal, 2020; Nikabadi & Sepehrnia, 2019).

New product managers must encourage the adoption of new technologies by their team, so it will be possible to collect, transmit and analyze information more efficiently and use this knowledge to support decision making (Barczak, Sultan & Hultink, 2007). The use of technologies by these professionals can improve the effectiveness of NPD processes (Mauerhoefer, Strese & Brettel, 2017).

In summary, new product development processes encompass several activities that begin with identifying opportunities and end with the launch of the product on the market (Nikabadi & Sepehrnia, 2019). The use of ICT has a positive effect at different stages of the NPD process and can help the development of successful products for the market (Barczak, Sultan & Hultink, 2007; Durmuşoğlu & Barczak, 2011). Companies that have greater ability to use new technologies have a more effective and better performing NPD processes (Mauerhoefer, Strese & Brettel, 2017).

2.3 How IoT adoption can help companies in product development

Information-processing systems are essential in the process of developing new products because throughout all its stages there is a need to transmit data between different departments of the company and the use of information and communications technology (ICT) can assist the exchange of information collected by organizations (Ulrich & Eppinger, 2012). The adoption of new technologies impacts the internal processes of organizations and "it is imperative for firms to make use of information technology (IT) in new product development

(NPD) processes as they are information intensive" (Mauerhoefer, Strese & Brettel, 2017, p. 719). Durmuşoğlu and Barczak (2011) examined the usage of information and communication technology to develop products and the results indicated a positive effect of ICT in different phases of the NPD process. Ibrahim and Obal (2020) state that the adoption of new technologies for the development of new goods can generate competitive advantage for the company and improve the performance of the stages of the NPD process. The use of ICT and tools that facilitate the exchange of knowledge (e.g. internet, e-mail) contribute positively to the development of new products in organizations (Nikabadi & Sepehrnia, 2019).

Companies must identify opportunities from different sources, internal and external to the organization, so there is a greater likelihood of generating successful insights for the development of new products (Ulrich & Eppinger, 2012). Firms should collect and integrate multiples stakeholder information, which may be within the boundaries of the company or not, to assist in a new product development process (Yerpude & Singhal, 2018). In addition, smart products can generate data, such as information about performance and maintenance needs, and this information can also be used for improvement or development of new products (Cavalcante & Fettermann, 2019). The sources of information can be within the company (e.g. R&D, sales and marketing department) or outside the limits of organizations (e.g. consumer, suppliers, smart products) and in the process of developing new products it is necessary to integrate this data efficiently and effectively (Yerpude & Singhal, 2018; Yerpude & Singhal, 2019). The use of ICT is essential to integrate the internal and external information collected, this acquired knowledge positively impacts the creation of innovations in companies and improve the NPD processes (Kroh, Luetjen, Globocnik & Schultz, 2018; Nikabadi & Sepehrnia , 2019).

In this context the Internet of Things (IoT) can help to integrate data from different sources using an ecosystem formed by devices, sensors and system that can extract, transmit and analyze the information to create knowledge to the companies (de Sousa Jabbour et al., 2018; Fatorachian & Kazemi, 2018). The interconnectivity that characterizes this network of equipment helps from the design of new products to the improvement of internal processes in the production lines, for example intelligent devices can be installed in a vehicle that is being developed and the collected information can be used to create new designs as well as produce improvements related to the operation of engines and other internal components of the vehicle (Yerpude & Singhal, 2019). Dijkman, Sprenkels, Peeters & Janssen (2015) created a business model framework for IoT, based on interviews with professionals who work with this technology, and product development is considered a key activity related to the application of IoT in companies.

In addition, with IoT it is possible to use data in real time to generate insights for organizations in the process of developing new products, so this technology optimizes the internal processes necessary to create new goods for the market (Yerpude & Singhal, 2018). Real-time data sharing can more efficiently assist collaboration between departments in the organization and minimize inefficiencies in the process of developing new products (Yerpude & Singhal, 2019). This technology can collect and analyze product performance data during use, the outcomes generated can assist in the design of new products and increase the company's knowledge about the market (Taylor, Reilly & Wren, 2020).

The information collected needs to be analyzed and stored to help in the development of new products, in this context the Internet of Things can assist in this process by creating a network of interconnected equipment that allows this interaction and data exchange (Yerpude & Singhal, 2018). The data collected by IoT devices are diverse and voluminous and the companies needs to use a database management system to analyze this amount of information

to find patterns that can provide insights into new product development processes (Taylor, Reilly & Wren, 2020).

Information and communication technologies can help companies collect and analyze internal and external stakeholder's information to generate knowledge that can be used in different departments and improve innovation activities (Kroh et al., 2018). Many studies have found that the use of these technologies has a positive impact on NPD processes, but few address the impact of using IoT in this process (Barczak, Sultan & Hultink, 2007; Durmuşoğlu & Barczak, 2011; Ibrahim & Obal, 2020; Nikabadi & Sepehrnia, 2019; Mauerhoefer, Strese & Brettel, 2017). Companies can use IoT throughout the entire process of developing new products and the use of this technology can assist in reducing costs and lead-time in product development, in customer satisfaction and retention through the creation of products aligned with the demands of market (Yerpude & Singhal, 2019).

3. METHODOLOGY

This study used secondary case studies extracted from IoT ONE (https://www.iotone.com) database. Secondary data can be considered useful because through them it is possible to collect a large amount of data using fewer resources, reduce the researcher's bias in the data collection process and provides greater opportunity for replication of the study if the data are publicly available (Rabinovich & Cheon, 2011). IoT ONE is a research organization focused on the use of Internet of Things in industrial context, their database highlight successful adoption case studies of industrial IoT. The company describes itself as an "online knowledge center [that] gives technology suppliers a platform to showcase their technologies and capabilities, and technology end users a convenient source of information to track the development of the IIoT ecosystem" (https://www.iotone.com/faq, accessed 23 June 2020).

The information contained in the cases comes from the companies that developed the technology adopted and the data are disclosed in agreement with the consumer. The cases can provide information on applicable industries and functions, functional area that adopted the IoT, challenge, customer, solution applied, technology maturity, operational impact and quantitative benefits. The cases studies can be considered successful stories of adoption of the IoT in the industrial environment and will be used to carry out the analyzes contained in this article.

The objective of this article is to discuss how companies adopted Internet of Things in new product development processes. The operational impacts related with the IoT adoption in the case studies will be examined through a three-phased decomposition approach of NPD processes: discovery, development and commercialization of the new product. This approach was used by Durmuşoğlu and Barczak (2011) to examine the use of different information technologies across the NPD processes. In this analysis, all the selected case studies were fully read and it was possible to identify the challenge related to the implementation of the IoT, the solution developed and the operational impacts of IoT adoption in the NPD processes. The cases that are part of the sample have at least one operational impact related to the adoption of IoT in new product development processes.

The operational impacts of each case study were related to the phases that constitute the NPD processes (i.e. discovery, development and commercialization). The impacts were related based on the activities developed at each stage of the NPD processes, which are presented in

table 1. The purpose of this analysis is to discuss how the adoption of IoT impacts each process that compose the development of new products.

3.1 Data selection and sample

The data set was examined in June 2020 and on the "Case Studies" section the database included 1,191 cases. The cases were selected according to the following selection criteria: first, elimination of cases not discussing process control and optimization reduced the database to 357 cases. Second, selection of cases discussing product development as functional area reduced the database to 70 cases. Finally, missing information on operational impacts related with IoT adoption and technology maturity led to retain 54 cases studies.

4. CASE STUDIES ANALYSES

The information presented in this topic was extracted from the 54 cases previously selected using the sample selection criteria.

4.1 Descriptive analysis

Companies adopted the Internet of Things in 8 industrial sectors, the Equipment & Machinery sector has the largest number of cases (33) and represents 61% of the sample. Secondly are the Automotive, Energy and Transportation sectors that presented 4 cases each. Then we have Construction & Buildings (3), Chemicals (2) and Mining (1). It is important to note that we had 3 cases classified as Other industrial sector.

Technological maturity is presented according to the following classification criteria: cutting edge technology < 2 years, emerging technology between 2 and 5 years, mature technology > 5 years. In the selected sample, most of the technologies adopted were developed more than 5 years ago (24), followed by emerging technologies that are between 2 and 5 years old (22). Only 8 cases used recent technologies developed less than 2 years ago. Table 2 summarizes the applicable industries and technological maturity characteristics.

Table 2 - Sample characteristics

Variable	Number of cases	% of sample
Applicable Industries		
Automotive	4	7%
Chemicals	2	4%
Construction & Buildings	3	6%
Energy	4	7%
Equipment & Machinery	33	61%
Mining	1	2%
Transportation	4	7%
Other	3	6%
Technological maturity		
Cutting edge technology	8	15%
Emerging technology	22	41%
Mature technology	24	44%

In the sample of 54 cases, 38 different companies developed solutions related to the adoption of IoT in new product development processes and 9 companies contributed in more than 1 case. The company ThingWorx stands out as the one that most developed IoT projects for the NPD processes with 5 cases, in second place is the company Wibu-Systems with 4 cases. Ericsson and ZIN Technologies have each developed technological solution for 3 cases. Bsquare, IBM, Microsoft, SAP and Wind have each developed technological solution for 2 cases.

4.2 NPD processes analysis

The cases selected for analysis have at least one operational impact related to the adoption of the IoT to optimize and control new product development processes, in the selected sample we have a total of 112 operational impacts. The operational impacts that were not related to NPD processes were eliminated from this analysis, in this sense 22 operational impacts that were not associated with the research objective were eliminated. This exclusion criterion reduced the number of operational impacts analyzed to 90, however it is important to note that the elimination of operational impacts did not affect the number of cases analyzed and the sample of 54 cases was maintained.

Table 3 – Operational impacts by NPD processes

NPD process	Number of impacts
Discovery	18
Development	42
Commercialization	30

The development phase presented most of the operational impacts (42), followed by commercialization (30) and discovery of opportunities (18). Table 3 summarizes the number of operational impacts in each of the phases of NPD processes.

In the discovery phase of the NPD process, operational impacts related to the activities of identifying market opportunities, collecting and analyzing consumer data, generating an idea, testing the product concept with consumers and developing the specifications for the new item were analyzed. Table 4 presents the number of operational impacts at each activity of the discovery phase.

Table 4 – Operational impacts in discovery phase

Discovery Phase	Number of impacts
Identify market opportunities	8
Collect and analyze customer requirements	9
Generate product or service ideas	1
Test product concepts with customers	0
Develop a clear description of the selected product requirements	0

The IoT adoption in discovery phase had a greater impact on the activity of collecting and analyzing customer requirements, the use of this technology assists the collection and sharing of data from different sources and this aspect may have encouraged the use for the analysis of consumer information. The second activity that was most impacted is the identification of opportunities in the market and in the process of developing new products, in this context it is interesting to highlight the use of this technology to identify opportunities to save internal resources (e.g. electricity with more efficient processes). The generation of insights for products and services was impacted in just one case study. Testing product concepts with consumers and developing a better description of product requirements were activities that were not impacted by the adoption of IoT.

In the development phase of the NPD process, operational impacts related to the activities of translating the product requirements into a final design, testing the product and creating a concrete item ready for commercialization were analyzed. The integration of data from different departments, which is an important benefit of the IoT adoption, is related with activity of translation the product requirements into a final design. The increase in flexibility in product development systems or platforms are related to the creation of new products for commercialization. Table 5 presents the number of operational impacts at each activity of the development phase.

Table 5 – Operational impacts in the development phase

Development Phase	Number of impacts
Translate the product requirements into a final design	17
Test the product	5
Create a concrete product ready for commercialization	20

The IoT adoption in development phase had a greater impact on the activity of creating a concrete product ready for commercialization, most of the companies used this technology to increase the flexibility of the development system and platforms. The second activity that was most impacted is the translation of the product requirements into a final design, in this aspect it is important to note that most companies implemented IoT to facilitates the integration and exchange of information by different departments and stakeholders to assist in the development of a new product. The test of products was the activity less impacted by the IoT adoption.

In the commercialization phase of the NPD process, operational impacts related to the activities of formulating and executing the launch of the product, production ramp up, training the distribution and sales forces, purchasing media time and space, developing media messages were analyzed. The improvements in the manufacturing processes and the increase in the quality control of the items produced are related to the activity of formulating and executing the launch of the product. The increase in production capacity and reduction in the time needed to launch the product on the market are related to the production ramp up activity. Table 6 presents the number of operational impacts at each activity of the commercialization phase.

Table 6 – Operational impacts in the commercialization phase

Commercialization Phase	Number of impacts
Formulate, execute and synchronize the launch of the product	16
Production ramp up	13
Train the distribution and sales forces	1
Purchase media time and space	0
Develop media messages	0

The IoT adoption in commercialization phase had a greater impact on the activity of formulating and executing the launch of the product, in this aspect the companies have used this technology to plan and improve the efficiency of manufacturing processes (e.g. increased quality control of production lines). The second activity that was most impacted is the production ramp up, the IoT adoption at this stage helps to increase the production capacity and decrease the time needed to launch the product on the market. Only one company used this technology to train its professionals. Purchasing media time or space and developing of media messages were activities that were not impacted by the adoption of IoT in selected case studies.

5. CONCLUSION

This study has utilized secondary data on industrial IoT adoption to discuss the operational impacts of the IoT adoption in new product development processes. Many studies have found that information and communication technologies impact positively the NPD processes (Barczak, Sultan & Hultink, 2007; Durmuşoğlu & Barczak, 2011; Ibrahim & Obal, 2020; Nikabadi & Sepehrnia, 2019; Mauerhoefer, Strese & Brettel, 2017), but few articles address how companies are adopting IoT in new product development processes. The analyses

of 54 selected case studies allow to clarify how companies are adopting this technology in new product development processes and how these processes are impacted by IoT adoption.

The descriptive analysis identified the industrial sectors that have adopted IoT in NPD processes, the maturity of the technologies implemented and which companies developed the adopted solutions. In this sense, most of the companies used this technology in Equipment & Machinery sector. The use of IoT in this context allows the creation of ecosystems of intelligent equipment with the ability to collect and transmit information autonomously by different departments of the company. The most used technologies were developed more than five years ago, this possibly demonstrates that companies prefer to select more mature technologies compared to recent solutions. Companies are adopting technologies from several suppliers, 38 different companies provided IoT solutions for the 54 cases analyzed. In this sense, 9 suppliers contributed more than one case and the market seems to have a wide variety of companies that develop this technology for application in NPD processes.

The NPD processes analysis associated the operational impacts evidenced in each case study with activities related with three distinct phases of the NPD processes (i.e. discovery, development, commercialization). The purpose of this analysis is to discuss how the adoption of IoT impacts each process that compose the development of new products. The phase that suffered the greatest amount of operational impacts in the cases analyzed was development, followed by commercialization and discovery.

In discovery phase the IoT adoption mostly impacted the collection and analysis of customer requirements, in this sense the use of this technology permits the collection and sharing of data from different devices and this may have encouraged the use to analyze consumer information. The second activity that was most impacted by IoT was the identification of opportunities, in this aspect is important to highlight that many companies used this technology to identify opportunities to save internal resources in NPD processes. This technology was not used to test product concepts with consumer and develop a better description of product requirements.

In development phase the IoT adoption mostly impacted the creation of concrete products, this technology permits to increase the flexibility of the company's development system and platforms. The second activity that was most impacted by IoT was the translation of product requirements into a final design, in this sense the companies used this technology to facilitates the integration of information by different departments to assist the development of a new item.

In commercialization phase the IoT adoption mostly impacted the formulation and execution to launch the product, in this context most companies have used this technology to improve the efficiency of manufacturing processes. The second activity that was most impacted by IoT was the increase of production capacity. This technology was not used to purchase and develop media in the cases analyzed.

The study contributes to the current literature by discussing how companies are adopting IoT into new product development processes and how this technology is impacting activities related with these processes. From a managerial perspective the findings are relevant to understand how the adoption of this technology can help in the development of new products and what are the main operational impacts of the implementation of IoT in companies.

The study has some limitations that should be acknowledged. The case studies sample analyzed are not random and includes only success stories of adoption, in this sense the results obtained cannot be generalized.

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