Revista de Gestão
ISSN: 2177-8736
rege@usp.br
Universidade de São Paulo
Brasil

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Revista de Gestão, vol. 29, no. 4, 2022, October-December, pp. 367-379
Universidade de São Paulo
Brasil

Impacts of IoT adoption on NPD processes: optimization and control

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Received 29 January 2021
Revised 10 September 2021
5 February 2022
Accepted 18 February 2022

Abstract

Purpose – The Internet of Things (IoT) real-time data collection can help to more efficiently optimize and control companies' internal processes. Prior research analyzed IoT benefits and potential applications. Nevertheless, there is little empirical evidence and theoretical understanding of how IoT impacts new product development (NPD). This article aims at narrowing this gap.

Design/methodology/approach – In total, 54 case studies were selected from an IoT database – IoT ONE. IoT ONE has a section on NPD. NPD was divided into three phases: discovery, development and commercialization. The adopted IoT technology maturity level was also analyzed. A content analysis was carried out to identify the impacts of IoT in NPD.

Findings – This study's findings capture the emerging patterns of IoT adoption and its impact on NPD. Of the total, 33 IoT adoption cases in the sample were in the machinery and equipment sector. Adopted technologies were at least two years old in 85% of the sample. Only 15% adopted cutting edge technologies (less than 2 years old). Key actors (e.g. vendors) facilitate IoT adoption. By a small margin, the larger impacts of IoT were in the commercialization phase, where it was primarily applied to improve and optimize production processes, to better execute and synchronize new products launching, and to increase the factories' productive capacity. In the discovery phase, IoT was mainly used to identify new opportunities in the market and to collect customer data, to generate a better customer experience. In the development phase, IoT allows greater integration across departments, increasing internal collaboration and allowing more flexible NPD.

Originality/value – Many articles studied the impact of information technologies in NPD. Few address the impact of IoT in NPD. IT tells about the impact of better communications with relevant people. IoT tells about machine acquired information and knowledge. This is new, much broader and deals with quite different impacts on NPD.

Keywords Internet of things, New product commercialization, New product discovery, Technology adoption

Paper type Research paper

1. Introduction

The Internet of Things (IoT) is a network of interconnected devices that can autonomously detect and transmit data to humans or other devices, with the support of wireless sensor networks (WSNs), data analytics and cloud computing (Ancarani, Di Mauro, Legenvre, & Cardella, 2019; Gubbi, Buyya, Marusic, & Palaniswami, 2013). Data exchange within IoT is

Revista de Gestão
Vol. 29 No. 4, 2022
pp. 367-379
Emerald Publishing Limited
e-ISSN: 2177-8736
p-ISSN: 1809-2276
DOI 10.1108/REGE-01-2021-0017

done through wireless technologies. The most important for IoT is the WSNs and radio-frequency identification (RFID) (Xu, Xu, & Li, 2018). IoT is also essential for the successful implementation of Industry 4.0 (Frank, Dalenogare, & Ayala, 2019).

Companies can use IoT with different objectives, such as predictive maintenance of machines, internal resource use optimization, increase in quality control efficiency and new product development (NPD) processes (Yerpude & Singhal, 2019). In the process of developing new products, companies need to identify opportunities from different sources and select the best ones to create new products and services (Ulrich & Eppinger, 2012). The IoT is a technology that allows the constant exchange of information by different devices inside or outside the organization. In this manner, IoT helps organizations to create important insights for the development of new products (Yerpude & Singhal, 2019).

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 various sources and can create knowledge for companies in different departments (de Sousa Jabbour, Jabbour, Foropon, & Godinho Filho, 2018; Fatorachian & Kazemi, 2018). IoT facilitates the creation of products aligned to consumer demands and the cost reduction in the NPD processes (Yerpude & Singhal, 2019). IoT enables the collection and analysis of data in real-time, which allows the optimization and control of the NPD processes, making them more effective (Yerpude & Singhal, 2018).

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 has analyzed benefits and potential applications associated to IoT adoption, although there is little empirical research concerning its impact on operations that are pursuing to optimize and control the product development process. The objective of this article is to discuss the operational impacts of IoT adoption on new product development processes. This study seeks to answer what is the actual impact of IoT on NPD. This leads to the following research question:

RQ1. What is the impact of IoT use in the NPD processes?

The study exploits secondary data to contribute to the answer to the question. An IoT database, further described below, provided case studies to shed light on the operational impacts – related to the adoption of IoT – on NPD. The cases provide information on applicable industries and functions, functional areas that adopted the IoT, challenges, customers, solutions applied, technology maturity and operational impacts.

This article begins with the theoretical background, providing an overview of IoT, NPD processes and the adoption of that technology in this context. Second, the methodology is presented, followed by the case study analyses. The last topic contains the conclusion.

2. Theoretical background

2.1 IoT overview

The IoT is a network formed by machines, sensors, systems and interconnected products, which are programmed to collect and transmit data, enabling the tracking and monitoring of different types of devices that are integrated to this technology (de Sousa Jabbour *et al.*, 2018; Fatorachian & Kazemi, 2018). IoT is a technology that works as a basis for the adoption of Industry 4.0 in organizations (Frank *et al.*, 2019).

The devices, or “things”, connected to the IoT must have a communication standard that allows the interoperability of the system, enabling the autonomous date exchange between different types of equipment with intelligent interfaces (Xu *et al.*, 2018). Radiofrequency tags (RFID) and WSNs are technologies that have helped the development of the IoT: 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 RFIDtags and sensors, have evolved and become more sophisticated (Singh & Bhanot, 2019).

IoT can assist in various departments of a company because this technology allows collecting relevant data from different sources, systematically analyzing the information to generate knowledge for organizations, and supporting strategic decision-making (Taylor, Reilly, & Wren, 2020). This network can 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 data collected in real-time helps communication between different departments of the company and stakeholders (e.g. marketing, R&D, consumer), and benefits the product development process in organizations (Yerpude & Singhal, 2018, 2019). This technology can provide market information "without the usual costs associated with customer surveys and focus groups" (Taylor *et al.*, 2020, p. 153).

Wireless communication, sensor networks and smartphones will continue to evolve and this will permit more networked things to connect the IoT (Xu *et al.*, 2014). The technological advancement of the last few years makes it difficult to predict a future without the interaction among smart devices to generate benefits for humanity, so the IoT has enormous potential for application in different contexts in society (Singh & Bhanot, 2019). 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 are relatively less studied" (Ibrahim & Obal, 2020, p. 5).

2.2 New product development (NPD) and IoT

The development of new products is important to maintain an organization's competitiveness in the long term and for a successful launch, it is essential to capture and understand market demands (Nikabadi & Sepehrnia, 2019; Yerpude & Singhal, 2019). Companies that can develop a product aligned with consumer expectations, and with agility, can create a competitive advantage (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 can 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).

Firms create new goods through NPD 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, and 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.

New product development processes require efficient integration between multiple organizations' activities to facilitate the exchange of knowledge (Nikabadi & Sepehrnia, 2019). New technologies can help professionals who develop new products in the process of integrating the wide variety of information collected by the organization, therefore, the adoption of new information and communication technologies (ICTs) can assist in increasing productivity and support in the phases of the NPD process (Ibrahim & Obal, 2020; Nikabadi & Sepehrnia, 2019).

The use of technologies by these professionals can improve the effectiveness of NPD processes, assist in identifying opportunities from different sources, and increase the productivity and efficiency of such processes (Ibrahim & Obal, 2020; Mauerhoefer, Strese, & Brettel, 2017; Nikabadi & Sepehrnia, 2019). These technologies can favor the development of successful products for the market and make NPD processes more effective (Barczak, Sultan, & Hultink, 2007; Durmuşoğlu & Barczak, 2011; Mauerhoefer *et al.*, 2017).

Information-processing systems are essential in the process of developing new products, because throughout all the latter's stages there is a need to transmit data between different departments of a company, and the use of ICT can assist the exchange of information collected by organizations (Ulrich & Eppinger, 2012). Durmuşoğlu and Barczak (2011) examined the usage of ICT 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 a competitive advantage and improve the performance of NPD process stages. 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 improves the NPD processes (Kroh, Luetjen, Globocnik, & Schultz, 2018; Nikabadi & Sepehrnia, 2019).

In this context, IoT can help integrating data from various sources using a network formed by devices, sensors and systems that can extract, transmit and analyze the information to create knowledge for companies (de Sousa Jabbour *et al.*, 2018; Fatorachian & Kazemi, 2018). The interconnectivity that characterizes this network of equipment helps form 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 improvements related to the operation of engines and other internal vehicle components (Yerpude & Singhal, 2019). The outcomes generated using IoT can assist in the design of new products and increase the company's knowledge about the market (Taylor *et al.*, 2020).

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, customer satisfaction and retention, through the creation of products aligned with the demands of the market (Yerpude & Singhal, 2019).

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 and develop a clear description of the selected product requirements
Development	Translate the product requirements into a final design, test the product and 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, and develop media messages

Source(s): Adapted from Durmuşoğlu and Barczak (2011)

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 provide greater opportunity for study replication in case data are publicly available (Rabinovich & Cheon, 2011). IoT ONE is a research organization focused on the use of the IoT in an industrial context and their database highlights industrial IoT's successful adoption in case studies.

This secondary database was chosen because the information is publicly available, and the cases listed cover different companies and industrial sectors, enabling the collection of a wide range of information regarding the adoption of IoT. In addition, this database has already been used in another scientific article that aimed to create a taxonomy of IoT projects (Ancarani *et al.*, 2019).

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, the solution applied, technology maturity, operational impact and quantitative benefits. The case studies can be considered successful stories of IoT adoption in the industrial environment and will be used to conduct the analysis contained in this article. On the other hand, it is important to highlight that the use of secondary data can generate risks to the validity and reliability of the results.

3.1 Data selection and sample

The data set was examined in June 2020, and in the "Case Studies" section the database included 1,191 cases. The IoT ONE database classifies cases according to IoT usage into 88 different groups. In this work, the objective is to analyze the impacts of using this technology to optimize and control NPD processes. Thus, 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, the selection of cases discussing product development as a functional area reduced the database to 70 cases. Finally, missing information on operational impacts related to IoT adoption and technology maturity led to remaining 54 case studies.

3.2 Data analysis

Once the sample of the secondary case studies was selected, the first stage was to read them to identify the type of industry, the technological maturity, the challenge and solution developed by the companies and the operational impacts arising from the adoption of the IoT in NPD processes. The cases that are part of the sample have at least one operational impact related to the adoption of IoT in NPD processes, and all of them inform the maturity of the technologies adopted.

Content analysis was used to examine the operational impacts related to IoT adoption on NPD processes and technological maturity. This analysis is useful for categorizing theories through textual data analysis and to creating insights through the analysis of previous information (Flick, 2004).

The operational impacts were analyzed using a three-phased decomposition approach of NPD processes: discovery, development and commercialization of the new product. This approach is based on the article by Durmuşoğlu and Barczak (2011), which examined the use of different information technologies across the NPD processes. The operational impacts of each case study were related to the phases that constitute the NPD processes (i.e. discovery, development and commercialization) and were classified based on the activities developed at each of its stages, which are presented in Table 1. The purpose of this analysis is to discuss how the operational impacts of adopting IoT relate to NPD processes. The technological maturity was analyzed based on the classification criteria proposed by the secondary database used: cutting edge technology <2 years, emerging technology between 2 and 5 years, and mature technology >5 years.

4. Findings

The information presented in this topic was extracted from the 54 cases previously selected using the sample selection criteria. First, a descriptive analysis of the sample will be presented and then the content analysis of the cases.

4.1 Sample analyses

Companies adopted the IoT in eight industrial sectors: equipment and machinery sector has the largest number of cases (33) and represents 61% of the sample. Secondly, comes automotive (4), energy (4), and transportation (4) sectors. then we have construction and buildings (3), chemicals (2) and mining (1); three cases were classified as other industrial sectors.

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

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

4.2 Operational impacts of IoT in new product development processes

The cases selected for content analysis have at least one operational impact related to the adoption of IoT to optimize and control new product development processes: in the selected

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

Table 2.
Sample characteristics

sample, we have a total of 112 operational impacts. The operational impacts that were not related to NPD processes were eliminated from this analysis: 14 eliminated for that reason. The eliminated operational impacts dealt with topics such as environment, cost, infrastructure and security, and were not related to any phase or process of developing new products. This exclusion criterion reduced the number of operational impacts analyzed to 98; however, it is important to note that the elimination of operational impacts did not affect the number of cases analyzed, as the sample of 54 cases was maintained.

The commercialization phase presented most of the operational impacts (42), followed by the discovery (29) and development of opportunities (27). Table 3 summarizes the number of operational impacts in each of the NPD processes phases.

In the discovery phase of the NPD process, identified operational impacts related to the activities of identifying market opportunities, collecting and analyzing consumer data, generating an idea and developing the specifications for the new item. Table 4 presents the number of operational impacts at each activity of the discovery phase; the impacts were divided according to the technological maturity classification of each case.

The IoT adoption in the discovery phase had a greater impact on the activities of identifying market opportunities and collecting and analyzing customer requirements. Through this technology, it is possible to program smart devices to collect and analyze data in real-time (de Sousa Jabbour *et al.*, 2018; Fatorachian & Kazemi, 2018), so the application of IoT in companies can facilitate the process of identifying opportunities and collecting customer and market data. The improvement in the process of identifying new opportunities can be done through the implementation of big data analysis techniques in conjunction with IoT, so companies can analyze patterns in a wide variety of data to generate insights. The collection of user data helps to create a better shopping experience for the customer through customized offers. In this respect, it is interesting to highlight that three cases have used IoT to collect data from patients to generate better medical diagnoses and new health service opportunities.

The impact of IoT on generating new ideas for products and services is usually through the integration of information between different departments or users; this knowledge exchange helps to increase collaboration and facilitates the generation of new products and services. The use of this technology to develop a clearer description of the product's

NPD process	Number of impacts
Discovery	29
Development	27
Commercialization	42

Table 3. Operational impacts by NPD process

Discovery phase	Technological maturity Cutting edge	Emerging	Mature	Total of impacts
Identify market opportunities	2	4	4	10
Collect and analyze customer requirements	2	5	4	11
Generate product or service ideas	2	3	2	7
Test product concepts with customers	0	0	0	0
Develop a clear description of the selected product requirements	0	0	1	1

Table 4. Operational impacts in the discovery phase

characteristics was identified in only one case, which used IoT to identify and mitigate risks and issues in projects earlier, allowing more accurate planning of the product requirements.

In the development phase of the NPD process, identified operational impacts were related to the activity of translating the product requirements into a final design, testing the product and creating a concrete item ready for commercialization. Table 5 presents the number of operational impacts at each activity of the development phase; the impacts were divided according to the technological maturity classification of each case.

The activity that is most impacted by IoT is the translation of the product requirements into a final design. In this aspect, most companies implemented this technology to facilitate the integration and exchange of information by different departments and stakeholders to assist in the development of a new product. The use of IoT permits the connection of different systems and platforms involved in the creation of new products, aiding from the conception of the new item's characteristics to the manufacturing of a product ready for production and commercialization. Some companies used this technology to increase development systems' and platforms' flexibility. The use of IoT for product testing was identified in two companies that generated four operational impacts in this activity; the technology is used in this context to enable the simulation of the tests and monitor results in real-time.

In the commercialization phase of the NPD process, identified operational impacts were related to the activities of formulating and executing the launch of the product, production ramp-up, and training distribution and sales forces. Table 6 presents the number of operational impacts at each activity of the commercialization phase; the impacts were divided according to the technological maturity classification of each case.

The IoT adoption in the commercialization phase had a greater impact on the activity of production ramp-up: the use of this technology helps to optimize the production processes and can improve manufacturing efficiency (Kiel *et al.*, 2017). In this aspect, predictive maintenance is a benefit generated by the use of IoT in production lines in some cases, and it promotes the optimization and control of production processes, which in turn allows an

Table 5.
Operational impacts in the development phase

	Technological maturity			
Development phase	Cutting edge	Emerging	Mature	Total of impacts
Translate the product requirements into a final design	3	6	7	16
Test the product	0	2	2	4
Create a concrete product ready for commercialization	1	4	2	7

Table 6.
Operational impacts in the commercialization phase

	Technological maturity			
Commercialization phase	Cutting edge	Emerging	Mature	Total of impacts
Formulate, execute and synchronize the launch of the product	2	7	8	17
Production ramp up	3	11	10	24
Train the distribution and sales forces	0	0	1	1
Purchase media time and space	0	0	0	0
Develop media messages	0	0	0	0

increase in the productive capacity of organizations and decrease the time needed to launch the product onto the market.

In this phase of commercialization of new products, some companies used IoT to formulate, execute and synchronize the product launch. The technology allows the creation of an equipment network that can be programmed to facilitate the operational activities necessary for the creation and production of new products. One company used this technology to train its professionals in a more flexible training environment.

An interesting finding concerns that there were no cases in the test of product concepts in the discovery phase. Another one is that, in commercialization, "purchase media time and space" and "develop media messages" also did not present any cases. This lack of adoption questions three categories proposed by Durmuşoğlu and Barczak (2011).

5. Discussion

Analyzed companies use IoT in NPD processes especially in equipment and machinery. The use in this area is intuitive because this technology allows the creation of networks of programmed intelligent devices with the ability to sense, collect and transmit information autonomously by the company (Xu *et al.*, 2014). In 61% of our sample, this technology was applied to equipment and machinery to promote the creation of a network of interconnected devices that optimize various processes for the development of new products.

In the automotive sector, it is important to highlight that this technology was used in a company (Monday Motorbikes) that offers urban mobility services through motorbikes connected to the cloud. The technology is used to collect customer data to promote a better consumer experience and to provide important information in real-time, which can assist theft prevention and security. In addition, this technology was used by AMG, the high-performance division of Mercedes-Benz, to optimize the execution of tests on the engines produced. In the energy sector, most companies used this technology to identify opportunities for saving internal resources and improving the efficiency of operations in the productive processes. In the transportation sector, it is interesting to highlight the case of General Dynamics Corporation, an American aerospace and defense company, which used this technology to create a dynamic environment for testing and training its professionals, in which developers can test and debug flight software in a simulated model, minimizing the need for multimillion-dollar test hardware.

In the sector classified as construction and buildings, it is important to highlight the case of, the South Korean telecommunications company, SK Telecom, which adopted an IoT solution to create a stable Internet access environment throughout its building, providing greater integration between its systems and increased flexibility in developing improvements for their system. The chemical and mining sectors have presented cases in which companies have used this technology to improve their operations' electricity efficiency. The companies classified as others according to the IoT ONE base criteria presented cases that did not fit the other classifications: in this category, the companies used this technology to optimize their production processes and to support the implementation of other technologies such as cloud computing and big data analysis, which can help identify new opportunities for organizations.

The companies adopted technologies of different maturity levels. The biggest part of the sample used technologies created at least two years prior to this study; only eight organizations used technologies created less than two years before the research and therefore more recent. This possibly demonstrates that companies prefer to select more mature technologies compared to recent solutions, maybe to mitigate risks related to the process of implementing this new technology. The technological IoT solutions were created by 38 different companies for different demands, so this market has many suppliers and is not concentrated in a few companies. In this aspect, companies that intend to explore this new market may have a difficult entry due to the high number of competitors.

The adoption of IoT causes more operational impacts in the commercialization phase of new products. In this aspect, 42 out of the 98 operational impacts analyzed were related to this stage. Most of the impacts in this stage were classified in the activities of formulation, execution and synchronization of the new product, and the increase of the productive capacity of the new item. In this aspect, it is important to emphasize that the adoption of this technology helps in the optimization and control of production processes that can smooth out the commercialization stage (Kiel *et al.*, 2017). Only one company used the IoT to assist in the training of its professionals, so there is an opportunity to explore the use of this technology in this sector, especially due to organization's human resources area's demand. No company has used this technology to develop and execute communication strategies, although IoT allows integration with equipment and systems that are beyond the boundaries of the corporations, such as social media; so, there seems to be an opportunity to explore this technology for this media purpose. In this aspect, it is important to emphasize that this technology can be used to assist in communication strategies because it is possible to generate more knowledge for companies about the market in which they operate (Taylor *et al.*, 2020; Yerpude & Singhal, 2019).

The second phase most impacted by the implementation of IoT was the discovery stage. In this respect, the activities of discovering market opportunities and collecting customer data were related to a total of 21 impacts, out of total 29. The operational impacts of adopting big data in operations help increase processing and analysis capacity and can assist in identifying new opportunities in the market (Taylor *et al.*, 2020; Yerpude & Singhal, 2019). The collection of consumer data helps to improve the consumer experience of products and services connected to IoT. Through this technology, it is possible to analyze information from internal and external stakeholders to the organization (Kroh *et al.*, 2018; Nikabadi & Sepehrnia, 2019). In this aspect, the use of this technology to monitor patients in real-time and generate more efficient diagnoses stands out. On the other hand, this activity can generate questions regarding the security and privacy of data collected by organizations. Only one company used this technology to better delineate the specifications of the new product: IoT was applied to identify errors in the project in advance, even in the early stages, to make development more agile and efficient. No company has used this technology to test product concepts with customers, despite IoT allowing for the acquiring of real-time feedback and direct integration with the user.

The development phase was impacted by 27 operational impacts out of total 98 analyzed. In this stage, the use of IoT in the activity of translating product specifications into a final model stands out. Many operational impacts analyzed helped to integrate information between different departments or users: this exchange of knowledge helps to increase collaboration and generate new products and services ready to be produced and marketed. IoT is a technology that enables the communication and integration of information between various departments and stakeholders of the organization, and this can increase internal collaboration and optimize the process of developing new products in companies (Yerpude & Singhal, 2018, 2019). Only two companies used this technology to ease the execution of tests on their products by creating more dynamic environments for conducting tests that can collect and analyze data in real-time.

6. Conclusions and implications to research and practice

This work studied secondary data about the operational impacts of industrial IoT adoption in NPD. Many studies have found that information technology positively impacts the NPD processes (Barczak *et al.*, 2007; Durmuşoğlu & Barczak, 2011; Ibrahim & Obal, 2020; Nikabadi

& Sepehrnia, 2019; Mauerhoefer *et al.*, 2017), but few articles address the impact of IoT on NPD. The sample and content analysis of 54 cases selected from the IoT ONE database help to clarify how companies are using IoT and its impacts on NPD.

From a theoretical perspective, empirical impacts are covering new product discovery, development and commercialization. The significant role of IoT in the machinery and equipment sector (61% in the sample) is already clear, and in this aspect, it is important to highlight that process control can be done without IoT adoption. This result demonstrates that even though companies can control processes without the help of IoT, many choose to adopt this technology in their machinery and equipment to increase control and optimization of NPD processes. It is also clear that most companies (85%) prefer to wait at least two years before specific IoT adoption in NPD. Moreover, 44% even prefer to await a mature IoT (more than 5 years old). This is in a database featuring company with experience in IoT, which means that early cutting-edge adopters will be much less in a sample without this limitation. Probably, a lot less. There is also a lot of vendors, promoting IoT adoption.

From a managerial perspective, IoT adoption can help to control and optimize NPD processes in its three main stages (i.e. discovery, development and commercialization) and this study highlights the processes most and least impacted by the use of this new technology in each of those phases. Professionals working in the development of new products can use the results of this work to create better strategies for the adoption of IoT for their businesses. It is important to note that there will probably be important differences concerning sectors, bold or more cautious strategies, and specific market situations.

The study has some limitations that should be acknowledged.

NPD processes may be divided into more phases than those shown in this study. Studies dividing NPD into more phases may provide more detailed findings concerning the precise impact of IoT on NPD and reveal novel patterns. Impacts were a little larger in the market phase, perhaps a sample effect that only further research will clarify. This study also showed and detailed the most relevant IoT activities, which could be better explored in future research.

The sample covers only IoT cases, is not random, and includes only success stories. Thus, results cannot be generalized, particularly to companies without any IoT adoption in NPD, and even less to companies in the early stages of IoT adoption. Furthermore, the use of secondary data can generate risks in terms of the validity and reliability of the results. In this aspect, there is an opportunity for future studies to address this same discussion with primary data collection to increase control over validity and reliability. The secondary database was chosen because the information is publicly available; nevertheless, the study of IoT adoption in the process of developing new products can raise some ethical questions regarding how organizations' data are collected and analyzed.

These limitations suggest many empirical research opportunities. What about the reasons for unsuccessful stories? What prompts the IoT adoption in NPD? What are, if any, the differences between cases in the IoT ONE database and others not reported there? What are the main ethical issues involved in using IoT in NPD?

In the same vein, three activity categories of Durmuşoğlu and Barczak (2011) did not appear in any case; "test of product concepts in the discovery phase", and, in commercialization, "purchase media time and space" and "develop media messages". Again, verifying these possible findings requires further research.

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