Industry 4.0 and Business Process Management: An Exploratory Study on the Bilateral Effects

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Abstract

The entry into the 4th industrial revolution, or Industry 4.0, caused a paradigm shift. The transition to new systems built on the infrastructure of the business processes digital revolution has given rise to new technologies. Digital Twin is one of the many technologies associated with this new concept consisting of a virtual representation of companies, being its main objective the replication and analysis of production systems in real-time. However, modeling business processes involving those digital ecosystems remains a pressing challenge both for companies and academia. This study aims to make an exploratory analysis of the evolution of Business Process Management (BPM) within the I4.0 paradigm, to understand how it has been able to keep up with these new trends. Several topics for future investigation are presented in this article as an outcome of this analysis.

Keywords
Business Process Management, BPMN, Industry 4.0, Cyber-Physical Systems and Digital Twin.

1. Introduction

The growth of the industrial world allied to the constant technological evolution has given rise to a new paradigm: the 4th industrial revolution. Common to all others, this new era also has as its central element a technological change. According to Kannengiesser and Müller (2018), technology has been integrated to announce the digital transformation in the production and its role as a milestone in the industry. With this revolution, new ones emerged, bringing changes in the way work is made, and making business processes more agile and autonomous. Some examples are Cyber-Physical Systems (CPS); Internet of Things (IoT); Machine Learning; Virtual and Augmented Reality, and more recently, Digital Twin (DT).

The evolution of technology that has occurred in the last decade, and the fact that it is increasingly accessible in terms of its acquisition by companies, made the DT one of the biggest trends concerning technological strategies. Furthermore, the contributions of the IoT have enabled DT to become economically more viable, representing an imperative tool for companies (Miskinis, 2019). However, despite these various approaches for successful vertical and horizontal incorporation of integrated production through CPS, business processes design involving digital ecosystems remains a pressing challenge (Kannengiesser *et al.*, 2015). With process design failures, companies give

up even before reaching the digitalization stage, as they are faced with a need to restructure their business processes. That way, BPM came to allow this process-oriented organizational management by providing different tools that have also been evolving over the last years (Baiyere *et al.*, 2020).
This article intends to explore the relationship of these two concepts – I4.0 and BPM – to understand if there is a clear evolution from BPM during the transition to digital environments in the context of the 4th industrial revolution.
For that purpose, the present paper is structured as follows: Section 2 gives a theoretical background on the concepts associated with I4.0 and BPM. Section 3 reflects on the role of BPM in I4.0 and is divided into two parts: (i) a first part that deepens the impact of I4.0 technologies on BPM; (ii) and a second part that studies the evolution of BPM within this context, which results in some research questions. A conclusion about this reflection is followed in section 4.

2. Literature Review

BPM represents a compilation of methods, procedures, tools and systems that helps to identify, analyze, redesign, implement and monitor processes (Dumas *et al.*, 2013). All these stages compose what it calls the BPM lifecycle. After the monitoring phase, the processes must be subject to a new analysis, resulting in a cyclical operation (Wurm *et al.*, 2019). Authors agree that a process orientation of a management system can only be achieved by applying this process approach (Závadský and Závadská, 2014). More recently, Business Process Management Systems (BPMSs) provides software systems that are responsible for controlling and monitoring the activities carried out in an organization, through an automatic execution of the various stages (Satyal *et al.*, 2019).
To achieve this management system and to harmonize the BPM concept with the standardization, there was a need to create a universal modeling language that could be understood among all stakeholders. The Business Process Model and Notation (or simply BPMN2.0), developed by the Object Management Group (OMG) is one of the most widely used notations due to its versatility and ability to represent business processes within the different purposes (Corradini et al. 2018; Corradini et al., 2018). Moreover, its "potential for consolidating the market of process standards is emphasized by its subsequent acceptance as an ISO standard" (Baiyere *et al.*, 2020).
However, due to the increased complexity of processes in an industrial world in constant technological evolution, decisions have become more unpredictable, which makes it impossible to represent through simple and pre-defined decision points. Therefore, other languages have emerged as a way to answer the increased needs, such as the Case Management Model and Notation (CMMN). This model was developed to support real-time decisions that require high flexibility in case control, thus allowing the mapping of activities whose occurrence cannot be anticipated (Wiemuth *et al.*, 2017). On the other hand, also the Decision Model and Notation (DMN) was created for the management, representation and implementation of decisions (Object Management Group, 2016), which allows its modeling as that of its requirements and can be used alone or as a complement to BPMN and/or CMMN (Wiemuth *et al.*, 2017). Finally, the Subject-Oriented Business Process Management (S-BPM), first proposed in 1994 but which has gained relevance with the entry of Smart Factories, is introduced as an approach based on communication (Kannengiesser and Muller, 2013). It relies on a decentralized view where processes are assumed as interactions between process-centered functions, called "subjects" (Kannengiesser and Müller, 2018). In that way, the same authors argue that it is possible to model with "wider participation of various stakeholders" in a more democratized way, then allowing to model in "different process parts at different times" resulting in a greater acceptance of the obtained process models.
With the 4th industrial revolution, the paradigm has changed, focusing now on the digital transformation of the industrial processes and with the new technologies that have emerged. CPS (Plumpton, 2019), IoT (Belli *et al.*, 2019), Machine Learning (Paschek *et al.*, 2017) and Virtual and Augmented Reality (VR/AR) represent some examples that are integrated into the concept of I4.0 and that allow industrial processes to become more efficient, customized and autonomous (Klingenberg *et al.*, 2019). Cyber-Physical Systems for Production (CPPS), a variant of CPS, incorporate knowledge from other fields, like computer science, to process data and make decision points from the integration of the physical with the real world, by using distributed elements (Lins and Oliveira, 2020). More recently, the concept of DT is also associated with I4.0 as a bidirectional interaction between virtual copies of a system and its physical counterparts, being its main objective the replication and analysis of production systems in real-time (Cimino et al. 2019; Negri et al. 2017). In that way, an autonomous system or a user can make the most correct decisions using the digital world for this purpose about current and future productions taking place in the physical world. Together with CPS is used to describe that cyber and physical integration from where the concept of Smart Manufacturing (SM) takes place and consequently the one of Smart Factory (SF) (Tao *et al.*, 2019a).
What all these technological tools have in common is the change they cause in the processes and with that the need to rely on systems that allow their integration in the modeling of business processes arises. To serve as an example,

Process Management together with Machine Learning technology gave rise to a new domain, the Process Mining. This technique supplies several data-driven and process-centered approaches allowing to discover, monitor, and improve real-life processes by extracting knowledge from event-logs, available in several information systems. (Kalenkova *et al.*, 2017). Given the role that BPM can have in the acceleration of I4.0 solutions, a reflection on its impact in the I4.0 (and vice versa), based on studies reported in the literature, was conducted in this paper.

3. Reflection on the Role of BPM in the Industry 4.0

3.1 Impact of I4.0 Technologies on Business Processes

In the previous section, literature shows that the technologies associated with I4.0 have a fundamental role in the evolution of industrial processes. Artificial Intelligence (AI) through devices that can act in a "smart" way and its direct application on machines to give them access to data so that they can learn for themselves gave rise to what is known as Machine Learning. These two concepts brought great changes to the way of managing processes. The creation of algorithms that improve themselves with the increase in experience has changed the way in which decisions were made in companies (Paschek *et al.*, 2017). Consequently, since these decisions were mostly made by humans, the initial structure of the processes' activities also had to suffer from some adjustments. Another mandatory factor for change was the need for interoperability between artificial systems, both physical and digital. IoT came to allow this digital connection between everyday objects and the Internet, providing them with computational capacity while allowing better control over them. Industries adopted this concept through the inclusion of, for example, identification devices such as Radio Frequency Identification (RFIDS), installation of sensors to detect changes in state, actuators, products, and other objects equipped with identification devices connected to the Internet. In this way, the network connection allows the gathering and transmission of data between all company's equipment.

CPS come to integrate all these physical, computational and communication processes, which already include new mechanical and electronic objects. Through communication over IoT, it is possible to embody Smart Factories (SF), helping on the execution of tasks by workers and the machines. This is where the DT concept also comes in. Associated with the CPS, the DT introduces virtual models to a physical system so that simulations of the system's behaviors can be carried out in real-time, providing early feedback, and supporting decision making. However, to be feasible, these models must be as close as possible to the reality of the physical system (Tao *et al.*, 2019b). Therefore, these new technologies and equipment need to be supported by systems that allow the integration of their functionalities and the technology they bring to the processes, in the form of models. Only through its incorporation into virtual models is it possible: (i) to ensure a twin model of the organization / physical system; and (ii) to achieve the standardization of the real process in accordance with the virtual.

3.2 The Evolution of BPM in the context of I4.0

What usually happens in the company's real life is that despite the various approaches for successful horizontal or vertical incorporation of integrated production systems, designing business processes in digital ecosystems remains a pressing challenge (Kannengiesser *et al.*, 2015). The technologies associated with digitization are usually included in real processes without being mapped into models or standardized in their processes. The pace of work or the lack of specialized BPM teams often prevents management from focusing on processes. And so, they go for innovation without guaranteeing a standardization of the current state, much less of the technological changes that are being implemented in their daily routines.

Despite these constraints, it is extremely necessary that technologies and tools implemented are also mapped through business models, both to increase the company's knowledge and for a future digitization process by creating, for example, a DT. Processes mapping is essential to guarantee that the virtual copies of a system translate the reality as closely as possible (Rittmeier *et al.*, 2019). Also, standardizing them, making them visible to the company's employees and stakeholders facilitate their management. Furthermore, it retains knowledge within the company during staff turnover as well as saving time and money for the organization, while ensuring that activities are carried out at the right time and in the correct order (Castro and Teixeira, 2019).

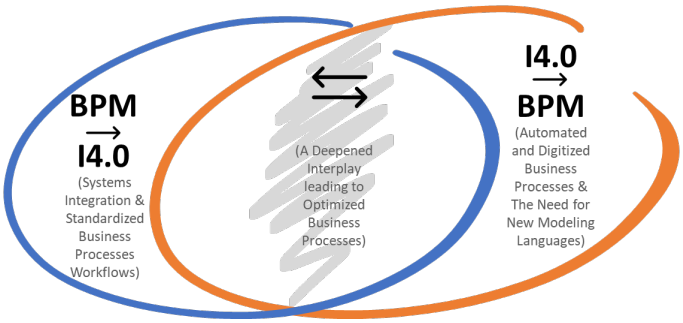
The new tools that have emerged within BPM, such as Process Mining suggest that BPM has been striving to meet new industrial needs. Similarly, the attempt to adapt some of the existing modeling tools allows inferences about the influence that I4.0 is having on BPM, as is the case with S-BPM (Kannengiesser *et al.*, 2015).

However, the literature also shows another reality. Liao, Deschamps, Loures, and Ramos (2017) in a review about the enablers of Industry 4.0 do not include Process Mining techniques. Marrella (2019) also states that in the face of new cyber-physical environments, there is still a lack of knowledge on the part of BPM professionals to be able to model all possible variants. Wiemuth et al. (2017) add that languages such as BPMN are no longer capable of handling

the high variability and need for process flexibility. Kannengiesser and Müller (2018), the same authors who introduce a new perspective on S-BPM also admit that more research is needed on the possible tool contributions to the existing approaches. A close look at the industries also suggests that BPM is also taking an isolated path, not being able to provide tools that enable the processes digitization.

This brief overview is part of an exploratory literature review that is being conducted by the authors. From a first analysis on the literature, no universal conclusion could be drawn with respect to a clear relationship between concepts. Among all information available consulted, only a minority seems to agree with the existence of a BPM contribution to the digitization paradigm. In the same proportion are the authors who defend an opposite evolution, proving the influence of I4.0 on the evolution of BPM. Therefore, most of the existing literature points to bilateral benefits over the last years.

Venn-Euler diagram in Figure 1 intends to graphically represent the set of possibilities of the relations between the concepts of BPM and I4.0, namely the intersection of the elements that results in the bilateral relationship between them explained so far. This diagram is dimensioned according to the new findings for a better clarification and



therefore a larger area is observed within the set resulting from that intersection.

Figure 1. Venn-Euler diagram representing the possible relationships between concepts as well as its main driven characteristics: Re-dimensioned in accordance with new findings.

Therefore, and contrary to what was initially expected by the authors, most state a direct and/or indirect existence of this relationship, especially as a bilateral relationship. Baars et al. (2014), for example, expounded that BPM and Business Intelligence (BI) have a deep interaction. Jain et al. (2001) also support the importance of the Virtual Factory (VF) to the continuous improvement changes which include new business processes. At the same time, authors complete their work with a different perspective regarding the integrated models that "allow validation of the integration of different functions inside a factory". Viriyasitavat et al. (2018) even include a framework on their work that summarizes the "three main benefits of Blockchain Technology (BCT) in BPM" while deepen saying that "BPM systems in Industry 4.0 are expected to automate service selections and compositions reliably and promptly with transparent interoperations of dynamic organizations". Polyvyanyy et al. (2017), Petrasch and Hentschke (2016), Feibert *et al.* (2017), Gomes *et al.* (2020), Knoch *et al.* (2019) as well as Kannengiesser and Müller (2018) also present bilateral perspectives in the use of these two approaches in their works. In the second case, authors explicitly introduce an "I4.0 process modeling language that is an extension of OMG's BPMN standard" driven by the need for "language extensions for aspects of Industry 4.0 application". Therefore, the emergence of new technologies that directly affect the activities that constitute the processes through their digitalization have shown to impact the way the processes are managed. This impact seems to have given rise to new management tools that enabled the development of new smart technologies.

In contrast, Hwang *et al.* (2017), Lederer *et al.* (2017), Appel *et al.* (2014), Kirchmer (2016) and Ismail *et al.*, (2017) only seem to present a more unilateral perspective on the subject, enhancing the importance of BPMN to the success of the virtual factory simulation. Lederer *et al.* (2017) go even further, arguing that the terms used today within the I4.0 come from other similar concepts that emerged within the discipline of BPM. However, Kirchmer (2016) refers a study that proving that "only 1 % of organizations have business processes in place that are agile enough to realize the full business potential of new digital technologies", meeting the problem raised in this review from the beginning. From the opposite perspective, one finds works that only directly mention "the other side of the coin". Some good examples are Baiyere *et al.* (2020), Suri *et al.* (2017), Repta *et al.* (2015), Afflerbach and Frank (2016), Marrella

(2019), Kerpedzhiev *et al.* (2020) and Pereira *et al.* (2019). Baiyere *et al.* (2020) argue that "digital transformation provides us with a unique opportunity to sharpen existing BPM logics and extend them beyond their theoretical limits". Kerpedzhiev *et al.* (2020) even assume that "the scope of BPM needs to expand". Figure 2 systematizes the opinion of several authors regarding the unilateral and bilateral effects between I4.0 and BPM.
That said, this analysis allows to conclude about the effective existence of a relationship between concepts although there is no consensus among all authors that this is a bilateral relationship, as is the case with Hwang et al. (2017). Regardless, a bilateral relationship is the one with the greatest advantage, ensuring the joint development of the different areas.

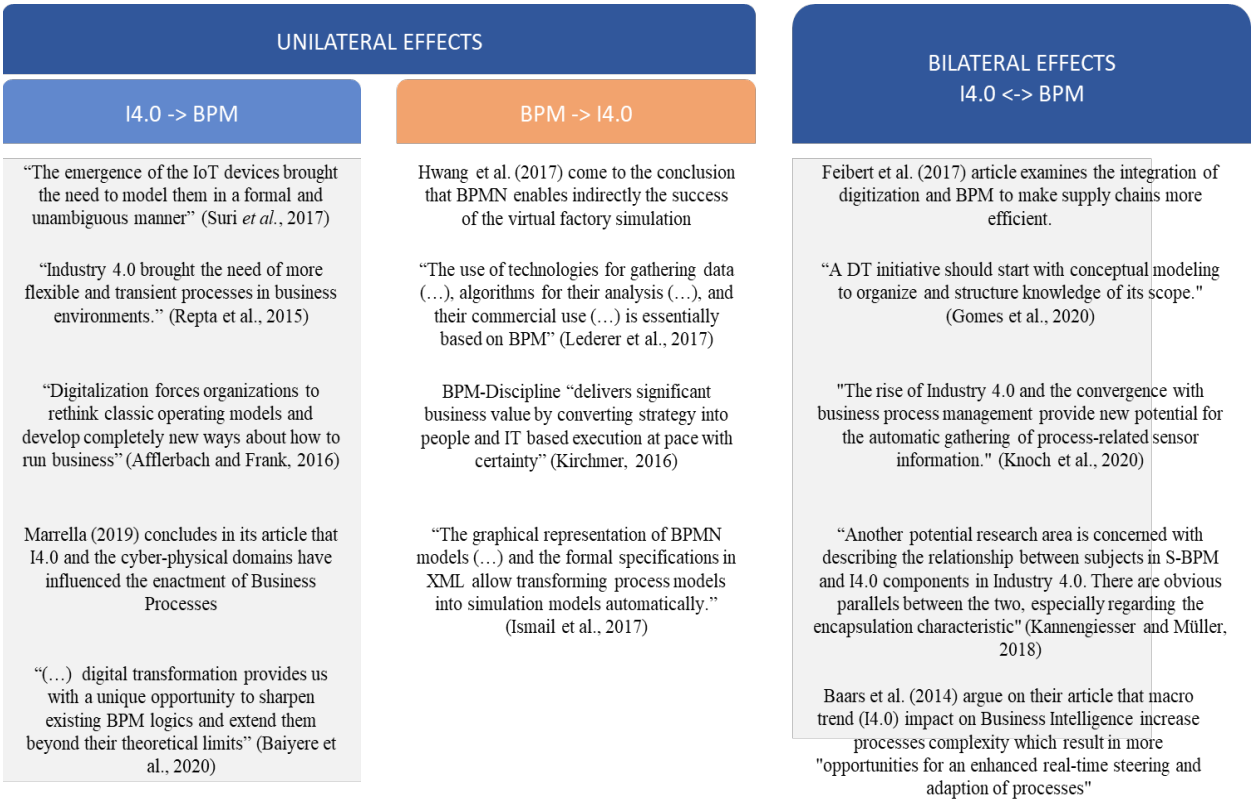


Figure 2. Some examples of the unilateral and bilateral effects resulting from the evolution of I4.0 and BPM, from the literature.

The lack of a measurable consensus proven trhouhout this article reflects the need for more solid and well-founded conclusions about this subject. Hence, a Systematic Literature Review (SLR) is being conducted by the same authors. With this SLR it is intended to fully understand those relationships, quantifying them and validate a possible bilateral contribution between the two fields, as well as the typology of industries being studied. Also, more information regarding the technologies associated with both concepts and more clear and specific contributions are expected to be highlighted.

4. Conclusion

This reflective study aimed to analyze the evolution of BPM within the concept of Industry 4.0. A careful preliminary search on the literature led to the conclusion that although there is no consensus among the scientific community, there is a remarkable interaction between them.
Processes management through standardization is at the basis of organizational excellence, even more for digitized industries where the information flow has a prominent place. Therefore, as future work, it is important to address some issues that arise at the end of this phase. To clarify the existence of a bilateral relationship between I4.0 and BPM, to qualify that relationship if exists and how BPM can enable I4.0 are some of those issues. Furthermore, it is important

to assess the level of process standardization awareness on companies with a digitization approach and to guide them in the introduction of new technologies for real existing industrial processes through new tools and frameworks.
To study the specific changes BPM went through and the integration of its existing modelling tools for a more flexible process mapping adapted to new industrial processes is also a priority. Thus, some of these questions must be answered by the academic community. To that end, it is being conducted a systematic literature review by the authors to help answer all those issues. This exploratory review should be seen as a starting point for the research that is being carried out in that direction.

Acknowledgments

This work was supported by Portuguese funds through the Institute of Electronics and Informatics Engineering of Aveiro (IEETA) and Foundation for Science and Technology, in the context of the project UIDB/00127/2020.

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Biographies

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