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IoT-aware Business Process: Comprehensive Survey, Discussion and Challenges

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***Abstract*—In the last years, the Internet of Things (IoT) know a huge widespread thanks to the increase of the connected objects number. The IoT technology has several benefits that make it among the proliferation technology. The major advantage of this technology is the communication between devices known as Machine-to-Machine (M2M) communication allowing them to be connected without human intervention. Thanks to this advantage, the technology become able to facilitate the people's lives that it become smoother through a seamless cooperation between virtual objects and physical ones. As well as, the IoT sweep various fields (e.g., industry, health) thanks to its capacity to automate tasks.**

In this setting, a tremendous number of business managers are interesting to integrate the IoT devices into their Business Processes (BPs), known in literature as *IoT-aware BP*. This integration gives the opportunity to the business managers to avail from the IoT technology in their process through an enhancement of the business performance and an achievement of the business competitiveness. Thus, several researchers competed to identify approaches and methods to integrate the IoT technology within the BP paradigm. In this paper, we present a review of the different proposed approaches that deal with the integration of the IoT technology within the BP. Furthermore, we give in this paper, a rich comparative analysis based on a set of criteria. Finally, we identify some initiatives and challenges in the IoT-aware BP paradigm.

***Index Terms*—IoT-aware Business Process, Internet of Things, Business Process, Industry 4.0**

I. Introduction

With the proliferation of communication technology, the Internet of Things (IoT) is gaining more and more attention. IoT is defined as a global computing network where everything will be connected to the Internet. Thanks to its benefits, e.g accuracy, speed, etc, the number of the connected objects will be raised every day. According to [1], there are in 2020 more than 30 billion connected objects around the world and in the future this number will increase to arrive more than 75 billion in 2025. These connected objects are spread in different areas with the aim to enhance people's lives. In this paper, we focus on the business managers, who aim at taking advantage of the IoT technology into the BPs in order to enhance productivity and performance of BPs and to facilitate the remote work without any worker displacement. In this regard, the IoT technology provides a promising opportunity to build a powerful industrial systems and applications [2].

In the business context, the I4.0 called also the Industry Internet of Thing (IIoT) has become among the prominent industrial business concepts in the last years [3]. Introduced in 2011, I4.0 is considered as the fourth industrial revolution. It appears after three other industrial revolutions which are respectively mechanization, mass production and automation. The I4.0 is defined as an extension of the IoT in the industry sector, which allows industry to improve the effectiveness and trustworthiness in their operations [4]. Also, it allows industry to enhance their transactions and operations by using sensors that raise production, optimize work and avoid system failures [5].

Therefore, it is interesting to have an overview of the main works that deal with the integration of the IoT technology in the business sector. However, in literature, there are few of surveys that address this issue and try to compare the existing works related to IoT-aware BP paradigm. In [6], authors describe the main requirements and concepts of the IoT-aware BP paradigm. Their analysis is limited to the popular business process modeling languages in order to identify which language can best be adopted as a basis for modeling IoT-aware business processes. However, we aim through this paper to give a comprehensive overview of studied work that deal with IoT-aware BP by comparing them according not only to the used modeling language but also to the considered concepts of IoT, the application areas, etc. The analysis of this work allowed us to identify the new directions to be addressed in the future.

The remainder of this paper is organized as follows. We define in section II a background of an IoT-aware BP. In section III, we survey the existing work related to the IoT-aware BP and we give a comparative analysis for the studied papers according to some identified criteria. In section IV, we give a list of challenges to be addressed in the future. Finally, in section V, we conclude this paper.

II. IoT-aware BP: background

This section is devoted to present the incorporation of the IoT technology within the BP (IoT-aware BP) and the relevance of this incorporation.

A. IoT-aware BP definitions

The IoT is among the most used and attractive technology in the last years [7]. Nowadays, this technology attracts the industrial field in order to integrate it in their BPs to improve their commercial act. This integration paved to appearance of a new paradigm which is IoT-aware BP. [8] and [9] define the IoT-aware BP as an aggregation of the IoT concepts with those of the BP, where the IoT executes part of the BP. However, [10] defines it as an interaction between the BP and the IoT devices in the aim to monitor BPs and to trigger actions on them.

B. IoT-aware BP relevance

The IoT-aware BP aimed, essentially, to facilitate the people's lives that it has become smoother through a seamless cooperation between virtual objects and physical ones. Moreover, the IoT technology allows the BP to gain time and enhance their provided quality by replacing the manual tasks by the automated ones.

The IoT-aware BP covers several fields such as the industry that it gave birth to the current industrial revolution I4.0 through an automation of the majority of tasks within the industries. This integration allows the industries to enhance their operations and transactions through an M2M communication without any human intervention. The IoT technology can be integrated also in the e-health process to enhance the healthcare services by monitoring the pressure of patients, their heart rates, etc.

Furthermore, IoT technology seems to be relevant for the business managers that intent to take a truth decision making during the execution of their BPs. While the traditional referential of data provides a historical data, integrating the IoT technology within the BPs allow the business managers to get the current data which are necessary to make the right decision.

C. IoT-aware BP: basic concepts

The IoT-aware BP groups both the BP concepts and the IoT concepts. The BP has several modeling languages, we note among them the Business Process Modeling and Notation (BPMN), Unified Modeling Language (UML), Petri net, etc. Actually, the BPMN is considered as the most used modeling language for a BP according to [11]. The BPMN 1.0 is the first version of BPMN, it was published in 2004. Then in 2006, the second version is the BPMN 2.0, which was adopted as a standard by the Object Management Group (OMG). The BPMN main concepts are defined by the OMG [12]. We present them briefly in what follows:

- Activity: presents a unit of work, which can be atomic or composite.
- Gateway: is an element that allows the control of a sequence flow.
- Pool: is a graphical representation of a participant e.g a company, which may contains some lanes. A lane presents a sub-participant e.g accounting service within a company.
- Event: presents something that occurs during the BP execution. The BPMN has several BP event types which are respectively start, intermediate, and end.
- Data Object: presents the information necessary for the BP execution. The data objects can be a singular object or a collection of objects.
- Message: depicts the communication between two different participants.
- Group: is a graphical element that aggregates other elements having the same characteristics.

The IoT-aware BP includes also the IoT concepts. According to the ISO/IEC 20924:2018 [1] standard, the IoT concepts should involve :

- IoT device: is an entity that interacts with other physical entities through sensors and actuators.
- Actuator: is an IoT device that has the ability to change the physical entity state.
- Sensor: is an IoT device which has the ability to measure the physical entity proprieties such as, temperature, speed, etc. The sensor sends the captured data to the actuator through a network as Wi-Fi, etc.
- IoT user: presents the user of the IoT device that can be a human or non human user.
- IoT gateway: is a set of network connectors which connect one or more networks to transfer information for an IoT device such as a router.

In contrast with the BP concepts, there is no standardized modeling language that defines the IoT concepts. Nonetheless, it is possible to extend BPMN to support the identified concepts and hence integrate them into a classic BP for an IoT-aware BP.

III. IoT-aware BP : overview and comparison

Bridging the gap between the physical world and the virtual world is, actually, among the fundamental IoT-aware BP aims. This objective can be realized by integrating the IoT concepts within the BPs. Thus, several researchers compete to propose different approaches to achieve this objective. In this section, we are interested to compare the main existing approaches in order to identify the main challenges of IoT-aware BP. We start, this section, by presenting our considered criteria required for the comparison and analysis of the existing works. Then, we give an overview of the studied approaches. Finally, we end by a comparative analysis.

A. Comparison criteria

In the following we give a description of each considered criteria that we consider relevant to compare the existing approaches for an IoT-aware BP.

- Concepts language/ formalism: is essential to identify the source of each used concept for both the IoT technology and the BP paradigm. The source can be an international modeling language (BPMN, UML, etc) or a formalism (ontology, etc). This criteria allows us to identify the most

[1] https://www.iso.org/obp/uiiso:std:iso-iec:20924:ed-1:v1:en

used modeling language/ formalism for the IoT-aware BP concepts.

- Application area: identifies the different areas that may include the IoT technology within the BP. It allows us to measure the importance and the usefulness of the IoT-aware BP in different fields.
- BP lifecycle: is defined according to [13] as a set of phases used during the BP creation. These phases are namely analysis, modeling, development and execution. We examine the proposed approaches to identify the considered BP phases once dealing with an IoT-aware BP.
- Considered IoT qualities : in literature, we distinguish three main qualities that are considered to evaluate the performance of an IoT-aware BP system. These qualities are namely the Quality of Things (QoT), the Quality of Service (QoS) and the Quality of Information (QoI). The QoT is defined as a set of attributes relevant to each thing's duty, such as the coverage, the mobility, etc. [14]. These quality attributes are used to evaluate the things performance. Usually an IoT offers a set of services with a certain quality (QoS). The QoS consists of a set of requirements that should be optimised to enhance the execution of a service [15]. These QoS may include time constraints, capacity costs, etc. The IoT services consume and produce data characterized by a QoI. The QoI is defined as a set of attributes (e.g., accessibility, relevancy, timeliness, etc) that measure the quality level of the used information in order to improve the quality of the provided information [16]. It is interesting to investigate which quality was considered by the studied works to evaluate the performance of their IoT-aware BP systems.
- Tools: refers to the used tools during the creation of an IoT-aware BP. This criteria allows us to identify the most considered tools for the integration of the IoT technology within a classic BP.
- The model flexibility: refers to the ability of the model to be adapted at runtime. It is worthy to check the dynamism of an Iot-aware BP model to determine if the proposed model can support changes or not.

B. Overview of the IoT-aware BP works

In this section, we review the most relevant research related to the incorporation of the IoT technology within the BP. Some works focus on the IoT-aware BP modeling phase. Towards this aim, [17] propose to extend both the Unified Service Description Language (USDL) and the BPMN 2.0 with the intention to propose an IoT-aware BP. However, their extended model is static and it was not performed by an execution scenario. [18] is among the works that targets the IoT-aware BP modeling issue. The authors propose to analyse which kind of event are necessary for the IoT-aware BP. In this context, they provide an extension for *Condition Event*, the *Message Event* and the *Error event* in order to integrate the IoT within the BP. Moreover, they add a new event called *Location Event* which allows the process users to identify the physical entity position. This approach uses both the IoT-A architecture[2] as a reference for the IoT concepts and the BPMN 2.0 for the BP concepts. Nonetheless, this work fails to be flexible and has not the ability to be adapted at run-time. Additionally, in [20], the authors extend the BPMN to incorporate the IoT within the BPs, thus they identify three concepts of the BPMN metamodel in order to represent an object within a BP which are Text Annotation, Data Object and Participant. However, among the limits of the propound model that is not applied on a real domain and it is a static. In [24] the authors suggest to add an element called 'ResourceRole' through a BPMN extension in order to define the source of data for an IoT task during the creation of an IoT-aware BP model. The authors use the IoT Solution protocol [3] as a based reference for the IoT technology concepts. However, the propound model fails to be dynamic and it does not consider any IoT qualities during the model creation. The authors, in [25], propose to define a model of an IoT-aware BP through an extension of the BPMN standard. They use the pool element to model the IoT device. Then, they translate their proposed model into Callas code [26]. Nevertheless, they do not consider any IoT qualities to check the performance of their extended model. In the same context, [19] propose a new method named *IoT-Aware Process Modeling Method (IAPMM)* that is based on a BPMN extension and it aims to integrate the IoT resources within the BP. The authors present the IoT device as a lane annotated thanks to a marker in order to distinct it from the other pools. Therefore, they use the IoT-A for the IoT technology concepts and both the BPMN 2.0, UML for the BP main concepts. However, this work fails to consider any IoT qualities to evaluate the IoT-Aware BP systems.

Another initiative is the one proposed in [23] in which the authors propose a semantic framework called *Internet of Things in Business Processes Ontology (IoT_BPO)*. The goal of the IoT_BPO framework is to facilitate the modeling and the management of the IoT resources within the BP. Therefore, the framework provides a formal description of the IoT resources and optimizes the management of these resources within the BP thanks to the IoT proprieties formalization. Besides, the proposed framework handles the IoT resource conflicts using a set of strategies. Towards this, they are based on the Business Process Modeling Ontology (BPMO) and the re-using of the existing IoT concepts from the IoT-Lite ontology [4]. Their approach may be enhanced by using data from various IoT test beds from different domains. Towards the flexibility issue, they propose in [27] a *Configurable Process Model (CPM)*, which aims to consolidate different process variants (several process solutions) into a customized process model via variation points called configurable elements (activity or gateways). While some works focus on the modeling and analysis phases, such other deal mainly with the execution phase of a BP life cycle. We cite [22] that proposes to improve the overall performance

[2]https://cordis.europa.eu/project/id/257521

[3]http://www.trusted- sol.com/servicesiot

[4]https://www.w3.org/Submission/2015/SUBM-iot-lite-20151126/

of an IoT-aware BP through a fragmentation of this model into a set of process fragments. To achieve this aim, the authors apply the Kuhn-Munkres algorithm [5]. In this level, the authors are interested only to execute an IoT-aware BP model without verification with any IoT qualities. Additionally, [30] and [31] propose a decomposition of an IoT-aware BP model into fragments in the intention to execute them on the IoT devices. Nonetheless, their proposals do not consider neither any quality of the IoT on their models nor any IoT formalism for modelling the used IoT concepts. In [34], the authors propose a new architecture called *Lean Automatic code generation for situation-aware and business-awaRe Applications (LAURA)* which is a conceptual architecture designed to support the deployment of decoupled IoT applications within the BPs. Nevertheless, the proposed architecture does not consider any IoT qualities to evaluate the performance of the IoT devices. In [21], the authors provide an end-to-end integration architecture of the IoT devices within the business process applications. However, they do not use any reference for the IoT concepts and do not consider any IoT qualities during the proposed integration.

Moreover, [29] offers another method for the execution of the IoT within the BP, it proposes a dynamic consistent hashing (DCH) algorithm to solve this problem and they analyse the feasibility of their approach through an IoT-aware BP application in the forest-protection scene. Nonetheless, among the major problem of this work that does not consider any IoT qualities during the proposed execution and it does not use neither a language nor a formalism for modelling the IoT concepts.

Actually, there are some new trends on the the IoT-aware BP execution. The execution on the Fog computing[6] is among the newest trends. In this context, we cite the [28] that deals with the IoT-aware BP at run-time level. At this stage, the authors have introduced a new middle layer composed of a set of Fog nodes distributed in order to execute some process parts. Nevertheless, this approach fails to use a language or a formalism for both the IoT technology concepts and the BP one. Some other work propose to execute the IoT-aware BP on Cloud computing [7]. We cite [33] that introduces an architecture to support the IoT service workflow processes on Cloud paradigm. The proposed architecture allows an integration of edge computing (sensor edge) for local data processing which is very crucial for life-critical IoT workflows and it facilitates the fast data transmission . However, the suggested architecture does not consider any language or a formalism for its IoT/ BP concepts. Another initiative [32] proposes to aggregate both the Fog and the Cloud paradigms during the IoT-aware BP execution. They propose an hybrid approach based on Fog and Cloud for dynamic planning of the IoT workflows. However, this works lack to use a reference for both the IoT concepts and BP concepts. Moreover, their approach was not validated with a use case scenario.

[5]https://www.researchgate.net/publication/290213864_Solving _the _Many

[6]https://dl.acm.org/doi/abs/10.1145/2342509.2342513

[7]http://faculty.winthrop.edu/domanm/csci411/Handouts/NIST.pdf

C. Comparative Analysis

Based on the aforementioned comparative criteria, we compare the available approaches as it illustrated in table I and table II.

We note that most of the existing approaches based their IoT concepts on a formalism like the IoT-Lite ontology and IoT-A. The IoT-lite ontology is a lightweight ontology of the IoT technology, it presents the main IoT concepts, services and resources. Whereas, the IoT-A is an IoT reference architecture that gives the guidelines of the IoT technology like its concepts, its used protocols, its mains applied algorithms, etc. Despite the used of the ontologies and the architectures, there is a lack of approaches that based their IoT-aware BP on a standard as the ISO/IEC 20924 for the IoT concepts. It is always useful to create models based on standards that provide a globally notations agreed with an international description for each noted notation and that lets to guarantee the credibility of each used concept.

However, for the BP concepts, most of the existing approaches used BPMN as a defacto standard for the BPs. They propose some extensions to transform a classic BPMN to an IoT-aware BP. Nonetheless, these extensions are various and depend on the analysis of the business process.

We denote also from table I that most of the proposed approaches are flexible. Indeed, using a flexible model allows an IoT-aware BP system to optimise its BPs. Also, referring back to table II, we note that several of the proposed models lack to consider some of IoT qualities despite their relevance. In fact, the evaluation of an IoT-aware BP regarding some qualities allows to check its efficiency, its reliability, etc. Thus, a process manager is able to enhance the IoT-aware BP performance. Moreover, according to our analysis, we notice that there is a tendency of execution of the parts of the PBs on external environments like Fog computing and the Cloud computing. This outsourcing allows companies to release the execution burden of some activities, to save time and to improve their productivity.

IV. Challenges

In this section, we give the significant list of challenges to be addressed by an IoT-aware BP model.

- The main concepts of a proposed model should be built on well defined standards for both the IoT technology and the BP. Examples of standards include the ISO/ IEC 20924:2018 as an IoT standard, the working standard Web of Things (WoT) defined by the World Wide Web consortium (W3C), which is intended to enable interoperability across IoT platforms and application areas [35], and the BPMN as the defacto standard for BP modeling.
- The proposed model should consider some IoT qualities such as the QoT, QoS and QoI in order to improve the performance of an IoT-aware BP.
- Proposal of a dynamic and flexible IoT-aware BP model is among the future challenges. The flexibility allows the

TABLE I
COMPARISON OF SELECTED APPROACHES ON IOT CONCEPTS, BP CONCEPTS, APPLICATION AREA AND MODEL FLEXIBILITY

Years	Approaches	IoT concepts language/ formalism		BP concepts language/ formalism		Application area	The model flexibility
		Language	*Formalism*	*Language*	*Formalism*		
2014	[17]	-	-	BPMN 2.0	-	-	No
2015	[18]	-	IoT-A architecture	BPMN 2.0	-	Agriculture	No
2015	[19]	-	IoT-A architecture	BPMN/ UML	-	Home security	No
2015	[20]	-	IoT-A architecture	BPMN 2.0	-	-	No
2015	[21]	-	-	BPMN2.0	-	AAL system	Yes
2016	[22]	-	-	BPMN	-	management system	Yes
2017	[23]		IoT-Lite/IoT-A reference model	BPMN 2.0	BPMO	Agriculture	Yes
2017	[24]	-	IoT Solution protocol	BPMN	-	Monitoring Environment	No
2017	[25]	-	-	BPMN	-	Agriculture	No
2018	[27]	-	IoT-A framework	BPMN 2.0	-	Agriculture	Yes
2018	[28]	-	-	-	-	Health	Yes
2019	[29]	-	-	BPMN 2.0	-	Protection system	Yes
2019	[30], [31]	-	-	BPMN	-	Agriculture	Yes
2019	[32]	-	-	-	-	-	Yes
2020	[33]	-	-	-	-	Health	Yes
2020	[34]	-	IoT-Lite/IoT-A architecture	BPMN/UML	-	Smart world	Yes

TABLE II
COMPARISON OF STUDIED APPROACHES BASED ON BP LIFECYCLE, IOT QUALITIES AND TOOLS

Years	Approaches	BP lifecycle				Considered IoT qualities			Tools
		Analysis	*Modeling*	*Development*	*Execution*	*QoS*	*QoT*	*QoI*	
2014	[17]	-	-	-	-	-	-	✓	-
2015	[18]	-	✓	✓	-	-	-	✓	-
2015	[19]	✓	✓	-	-	-	-	-	Sys ML
2015	[20]	✓	✓	-	-	-	-	-	-
2015	[21]	✓	✓	✓	✓	-	-	-	CoAP, jBPM
2016	[22]	-	-	-	✓	-	-	-	jBPM
2017	[23]	-	✓	✓	✓	-	-	✓	Signavio
2017	[24]	-	✓	-	-	-	-	-	BPMN tools
2017	[25]	-	✓	✓	✓	-	-	-	Eclipse IDE, jBPM
2018	[27]	-	✓	✓	-	-	✓	✓	Signavio
2018	[28]	-	-	✓	✓	-	-	-	-
2019	[29]	-	✓	✓	✓	-	-	-	Eclipse, BPMN plugin
2019	[30], [31]	-	-	-	✓	-	-	-	-
2019	[32]	-	-	-	✓	-	-	-	-
2020	[33]	-	✓	✓	✓	✓	-	-	Swarmprom
2020	[34]	✓	-	-	✓	-	-	-	Management tool, jBPM

business managers to intervene in any phase without any access issue.

- Outsourcing the execution of an IoT-aware BP on a Fog or a Cloud computing represents an attractive trend. This latter may facilitate the decentralization of the IoT-aware BP execution. Thus, the business managers may enhance the execution of their process and improve their production, etc.
- Proposal of a model that covers most of BP phases is a prominent challenge. The propounded model should be started by an analysis phase, that allows the business analyzer to identify the main constraints, requirement, and used tools. Then, it is significant to propose a model for each IoT-aware BP, these models facilitates the development action. Thereafter, it is crucial to develop the IoT-aware BP model by using a set of development tools. Afterword, the developed IoT-aware BP model must be tested via an execution of an IoT-aware BP prototype.

V. CONCLUSION

The IoT is an emerging technology that allows the communication between a huge number of things through a network. This technology attracts the business managers to integrate it into their BPs in the intention to avail from its benefits. Nevertheless, the integration is not a trivial task and remains difficult regarding the different characteristics of connected objects and BP elements. In this setting, several researchers attempt to resolve this problem through a proposition of IoT-aware BP approaches. In this paper, we present the relevance of the integration of the IoT devices within the BP (IoT-aware BP) and their basic concepts. Then, we give an overview of recent researches that deal with this issue. Furthermore, we proposed a comparative analysis of the studied works according to some identified criteria. Actually, we are working to propose a model for the IoT-aware BP via a BPMN 2.0 extension through which, we aim to consider some time constraints and other IoT qualities.

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