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# Modelling IoT Behaviour in Supply Chain Business Processes with BPMN: A Systematic Literature Review

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## Abstract

The Internet of Things (IoT) enables to connect physical world to digital processes, allowing real-world data to be fed into business processes. This revolution helps in the making of more informed business decisions as well as the automation and/or improvement of business processes tasks. The successful integration of IoT into business operations is required to realize these benefits. Supporting the modelling of IoT-enhanced business processes is the first step toward this goal. Despite the fact that numerous papers studied this topic, it is unclear what the current state of the art is in terms of modelling solutions and gaps. We conduct a systematic literature review in this work to determine how current solutions model IoT into business operations, and whether the standard Business Process Model and Notation (BPMN) has emerged as the de facto standard for business process modelling [20, 26]. The Object Management Group (OMG) developed BPMN, which is now an ISO standard BPMN is already enough for a full modelling of IoT integration, or the extensions are needed. We found and analysed the

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several existing alternative solutions after reviewing all the literature on this issue. Furthermore, we discuss some key aspects of the planned additions that should be addressed in the near future, such as the absence of standardization.

**Keywords:** Systematic literature review, business process modelling, BPMN, IoT, BPMN extensions, process execution, supply chain.

## 1 Introduction

Digitalization and shared information in real-time define a network of interconnected devices. Therefore, the constitution of IoT devices keeps growing. The range of applications is large and diverse, spanning from smart home environments to industrial situations [1], medical monitoring systems [2], and the digitalization of different activities in the manufacturing and supply chain fields.

However, more and more business processes are being used by different organizations to capture, manage, and optimize their activities. The need is more expressed in the global digitalization transformation that the world is going through [4]. In areas such as supply chain management and logistics, by utilizing the knowledge and capabilities of IoT devices, corporate processes can acquire a competitive advantage. Which allows moving towards integrated business processes.

This connected technology through all kinds of sensing devices, RFID, video identification, infrared sensors, and a global positioning system are all examples of cutting-edge technology (GPS), must be implemented clearly in the business process modelling to be measured interactively with the other component elements of the business processes. The supply chain management is linking large and different business processes including procurement management, inventory management, warehouse management, management of suppliers and distributors, and demand planning. Most of those processes maintained by different types of IoTs.

Thus, the need to continuously improve business processes and adapt to transformation makes most companies adopt a Business Process Management (BPM) strategy. BPM encompasses several activities, including business process automation, execution, and monitoring, but the modelling activity is the most important. Indeed, it enables the specification of business processes, which has a direct impact on the quality of a company's deliverables and, as a result, customer satisfaction. Furthermore, mistakes and

defects must be recognized during the modelling phase, when repair is less expensive and more tolerated.

Despite the existence of various modelling languages, BPMN has emerged as the de facto standard for business process modelling [20, 26]. The OMG developed BPMN, which is now an ISO standard (ISO/IEC 19510:2013). Because of its expressiveness, simplicity, and semantic richness, the BPMN language is frequently utilized. It is also supported by several tools, including Activiti, jBPM and Bizagi.

However, BPMN provides generic features and focuses on the functional requirements of Business Processes, it becomes constrained in supporting specialized domains or non-functional qualities. The OMG has proposed an extension system that allows users to incorporate new elements and provide legal BPMN extensions to overcome this issue and broaden the use cases of BPMN. Other modelling languages that provide extensions, such as UML, are more complicated than the BPMN language, which allows extension by addition. It consists of attaching new domain-specific elements to the predefined elements of the language [40].

Furthermore, rather than developing a Domain-Specific Modelling Language (DSML) from scratch, business process designers prefer to extend BPMN and reuse its kernel to take use of its benefits (e.g., standardization, tool support) [26]. As a result, a vast and growing number of BPMN extensions have been proposed in the literature, with goals ranging from the representation of domain-specific (e.g., healthcare, IoT, and manufacturing) to the improvement of the BPMN language itself (e.g., flexibility, complexity and variability). In addition, The BPMN isn't tied to any one expression language. The individuals in charge of business process modelling initiatives can choose any language they want.

In this study, we use Kitchenham [6] criteria to conduct a Systematic Literature Review (SLR) with the goal of determining the present state of the art of BPMN extensions for IoT domains and their integration in supply chain business processes, as well as identifying research requirements. An SLR differs from other forms of literature reviews in the way of conducting a thorough search of the literature and specifies the research issues that should be addressed [6]. The most recent literature study [3], focuses on extending the BPMN language to the best of our knowledge. The authors have classified extensions almost about the existing domain-specific where authors propose BPMN extension.

Our SLR will be specified for the IoT domain and its application in supply chain business processes. Indeed, after the research and filtering of

papers, BPMN extensions have been published for both IoT and what we call ubiquitous systems. The current paper will examine and compare those published extensions and its integration of our application domain of supply chain and logistics. To do so, we've created objectives, target domains, representation formats, compliance, implementation, and assessment criteria, among others.

By comparing our findings to those of [3] and [26], we hope to examine how the characteristics of BPMN extensions have evolved over the last few years and its application to supply chain management domain.

The rest of this report is laid out as follows. Section 2 provides an overview of business process modelling using BPMN, as well as an introduction to IoT integration in business processes, then in supply chain as a application domain. Section 3 describes the methodology followed in conducting our SLR. In Section 4, the integration of smart technologies in BPMN business processes is analysed and the obtained results of modelling with BPMN extensions or without are reported. The different tendencies in BPMN extensions for modelling smart technologies are discussed by the end of this section. Finally, Section 5 concludes this paper and offers suggestions for further research.

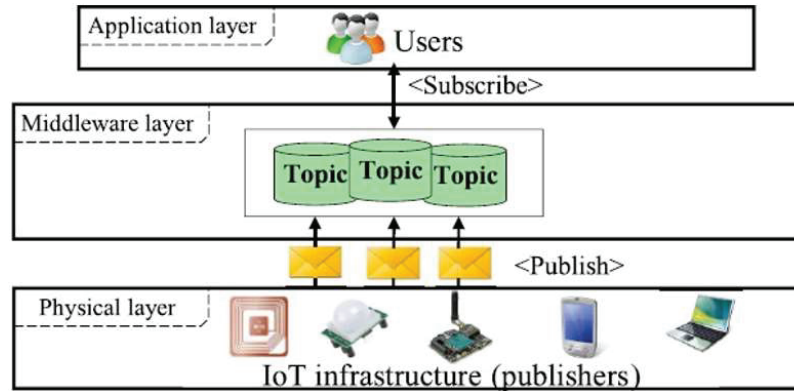
## **2 Background**

In this section, we highlight the main topics of this research that is based on the IoT and its integration in business processes modelling using BPMN in the specific domain of application, which is supply chain.

### **2.1 Internet of Things (IoT)**

The Internet of Things (IoT) is a concept becoming increasingly important in the managerial and engineering lectures. IoT is a network of physical objects such as devices, instruments, vehicles, buildings, and other items that are equipped with electronics, circuits, software, sensors, and network connectivity to gather and share data.

IoT enables objects to be sensed and controlled remotely across existing network infrastructure, allowing for more direct integration of the physical world into computer-based systems and better efficiency and accuracy [29]. IoT is able to interact without human intervention. In the supply chain healthcare, transportation, and automotive industries, some experimental IoT applications have already been developed.

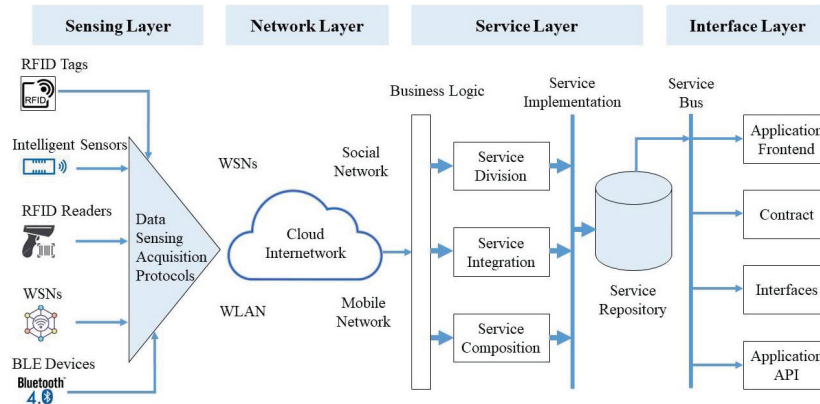


**Figure 1** Physical schema of IoT.

As shown in Figure 1, an IoT system is made up of three layers: a physical perception layer that includes a large number of sensors, actuators, mobile terminals, and sensor connectors and uses sensing technologies to sense physical objects (including humans) and social environments by collecting large amounts of data in order to convert them into entities in the cyber world; a network layer that includes all network components with heterogeneous network configurations (e.g., wireless sensor networks, adhoc networks, cellular networks); and a network layer that includes all network components with heterogeneous network configuration [27].

In an IoT, physical and virtual elements have their own identities and attributes, and they can use intelligent interfaces and be combined as a network of information. In simple terms, IoT can be defined as a collection of uniquely identified connected gadgets. The terms “Internet” and “Things” refer to a global network of interconnected sensors, communication, networking, and information processing technologies that could represent the next generation of Information and Communications Technology (ICT). Several technologies, such as Wireless Sensor Networks (WSN), are currently used in IoT.

Many variables are involved in the design of IoT architecture, including networking, communication, business models and procedures, and security. Extensibility, scalability, and interoperability among heterogeneous devices and their models should all be considered while creating IoT architecture. Because items may move and need to communicate with one another in real time, IoT architecture should be adaptable to allow devices to engage with one another dynamically and provide unambiguous event communication.



**Figure 2** Layers of IoT [29].

The architecture consists of four layers with distinguished functionalities that provide the interoperability among the devices in multiple ways [29] that are:

- Sensing layer is integrated with all available objects (things) to sense their status.
- Network layer is the infrastructure to support the wireless or wired connections among things.
- Service layer is to create and manage services required by users or applications.
- Interfaces layer consists of the interaction methods with users or applications.

## 2.2 IoT in Business Processes

Incorporating IoT into BPM has been the subject of recent research [1]. Because IoT is a technology that may be utilized to digitalize a system's context, the process is given the power to both understand and change its context using IoT devices. This was also emphasized in [13] implying that IoT technology can help in the concretization of abstract process models and the adaptation of processes to new contexts. As a result, IoT devices are utilized to digitalize various business processes and to include context into process execution. An abstract process model can be concretized in this way for context-aware execution [3]. IoT devices, on the other hand, are mostly employed to automate processes, particularly in supply chain and manufacturing domains.

### 2.3 IoT modelling with BPMN

IoT provides an opportunity to develop a new generation of business processes that take use of the IoT’s ubiquity by leveraging its computational, networking, and sensing capabilities. Parts of the business logic can even be executed by IoT devices.

BPMN has since evolved into a graphical standard for business process modelling and service description. It describes the semantics and syntax of a diagramming language. In business process modelling, BPMN has several advantages. BPMN provides a method for modelling process flows and workflows. The methodology has been tweaked to work better with business analytics modelling methods. Second, a solid mathematical foundation allows for direct conversion to business process execution languages [32].

We can only use standard BPMN [13] to specify IoT behaviour within business processes and at the same level of abstraction. To execute IoT processes, IoT devices must be linked to process elements as defined by the BPMN standard. The BPMN 2.0 standard provides a variety of ways for establishing this relationship. We have Tasks, Events, Resources, and Data among those mechanisms [1].

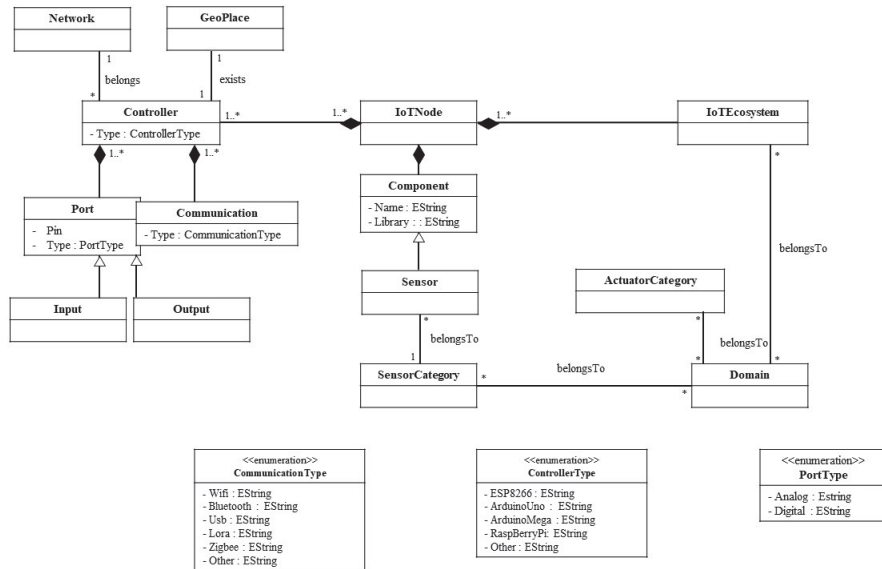


Figure 3 Metamodel of IoT Ecosystem according to [40].

Different abstraction ideas are used to tackle the modelling complexity of IT in business process modelling. Here we are seeking a vertical abstraction which allows to divide the core process model into subdomains like functions, information, organization, and IT landscape. Additional subdomains can be added based on the needs of the specific business process. The thing can be used to model IoT behaviour within BPMN.

## **2.4 Modelling Integration of IoT in Supply Chain Business Process with BPMN**

Faced with the challenges of global economic integration and the rapid development of computer communication and Internet technology, the range of logistics activities and logistics speed reach unprecedented levels of development, resulting in the emergence of an intelligent logistics system with high informalization and intelligence.

The demand for effective tools for process modelling, analysis, optimization, and automatic creation of applications fuelling these processes in IT systems grew as transportation, forwarding, and logistics focused operations grew in popularity.

In the information management strategy, supply chain informalization has been a critical challenge [30]. In addition, numerous research have focused on the goal and structure of an IoT-based intelligent logistics system and have developed an RFID-based logistics tracking and management system aimed at the manufacturing industry [31]. It is feasible to achieve synchronization between production, logistics, and information flow by relying on these IoT systems, boosting the efficiency and quality of logistics system operation, and strengthening the core competitive power of modern logistics firms.

- Use case:

Modelling the procurement process using RFID technology in order to ensure the equality of data, especially in retail domain of food that has short life date. In this case, the data should be communicated as soon as possible for its crucially. The following example (Figure 4) models' integration of RFID in procurement process between two entities (Supplier and Customer).

As shown, BPMN allows expressing the RFID behaviour as a certain modelling. RFID technology is being developed for the accurate operation of bottom-layer devices, real-time raw data collection, data filtering, and the encapsulation of typical application logic, resulting in a simple and transparent logistics management interface, making the entire system consistent and reliable.



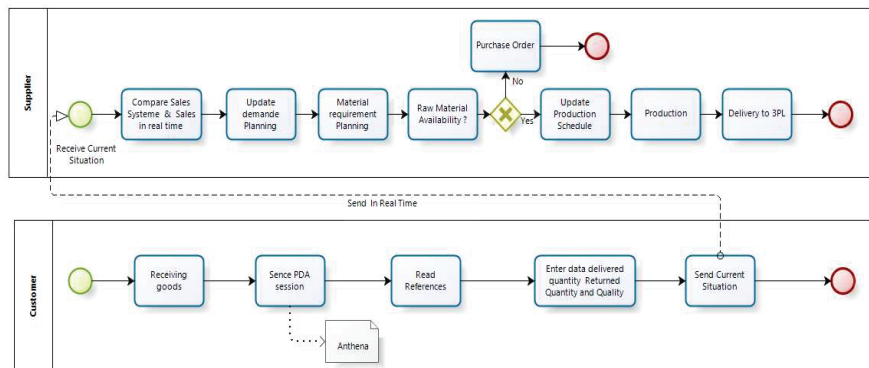


Figure 4 Information system using RFID in a procurement process.

### 3 Methodology

SLR is an approach that has been frequently used for various assessments in software engineering. It is a method of analysing and interpreting all available research on a certain research issue, topic area, or phenomenon of interest. *“The goal of systematic reviews is to provide a fair assessment of a study issue by employing a reliable, rigorous, and auditable methodology”* [13]. An SLR is a type of literature review that is defined by:

- A list of research questions that need to be answered.
- A thorough and objective search for relevant literature.
- An explicit definition of the criteria for inclusion and exclusion.

Primary studies that serve as the foundation for each type of study are defined as developing an SLR. There are various reasons why systematic reviews should be conducted, just as there are in other disciplines that use them. Here are a few examples:

- To summarize the available evidence about a technique or technology.
- To identify gaps in present research in order to decide where additional study may be required.
- To assist in the positioning of new research efforts.
- To see how much the available empirical evidence supports or contradicts a certain hypothesis.

As proposed for software engineering, the review process has three phases [5]: planning the review, conducting the review; reporting the outcomes from the review.

One of the main reasons for undertaking an SLR is to summarize and evaluate existing work in each research area, identify their gaps and suggest work to address them. Based on the guidelines depicted in Kitchenham [6], we conducted our SLR in several phases:

- (1) Developing research questions.
- (2) Extracting and filtering papers in a particular field.
- (3) Defining criteria for evaluation and comparison.
- (4) Presenting and discussing the findings
- (5) The rest of this section goes through each phase in further depth. .

### **3.1 Developing Research Questions**

Modelling IoT-based systems with business processes in the supply chain management is not successfully achieved, even though there is existing literature in this area. Those ones are not addressed to help out the managers to model smart processes in this application domain.

Therefore, it will be useful to address this issue and, in addition, to contribute to the existing literature work. This paper aims to address the questions that follow:

- RQ1. How much of the IoT Field came from BPMN's goals during the last few years?
- RQ2. What are the BPMN extensions and how are they expressed in different formats?
- RQ3. Do the suggested extensions adhere to the OMG's extension procedure and address the need for IoT integration in BPM?
- RQ4. How far is the standard BPMN is fulfilling the requirements for modelling IoT behaviour?
- RQ5. Is there any application in supply chain business processes?

### **3.2 Extracting and Filtering Papers in a Particular Field**

We built our search string first by combining the main terms "BPMN", "Extension" and "IoT" to find articles proposing modelling IoT business processes with BPMN. We replaced the keyword "BPMN" with "Modelling Language," and the phrase "extension" was replaced by numerous derivative words (e.g., "Extending"), as well as using "ubiquitous systems" to make the search as extensive as possible.

We used Google Scholar, Scopus, IEEE Xplore Digital Library, ScienceDirect, Emerald, SpringerLink, Google Scholar, AIS Digital Library,

INSPEC, and other databases and search engines. Our SLR includes all papers published in journals, conference/workshop proceedings, and book chapters that use BPMN to model smart technologies business processes. We employed terminology from the same semantic field in this study, and the final search string was organized as follows:

Search string = (“IoT” AND “BPMN” OR “Modelling language” AND “Exten\*” OR “Enhanc\*” AND “logistics” OR “Supply Chain”).

After running the search query over the digital libraries, we identified 96 research works potentially relevant for the research topic. The selection steps we applied are illustrated in Figure 5. Through a careful analysis of the title and abstract of these research works, we identified 20 relevant works.

Although other SLRs has been published for modelling IoT integration in business processes, they were considering many modelling tools other than BPMN as well. Our report’s selection went to a very precise criteria of the use of BPMN for modelling IoT behaviour because of our theme of research and the goal of defining the position of BPMN in this specific field and its application to supply chain domain.

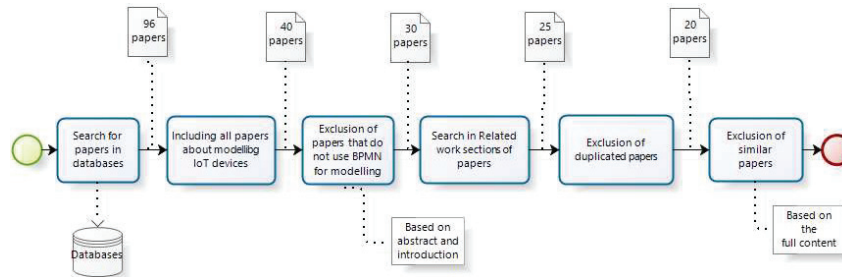
Several publications dealing with modelling IoT business processes have been identified in the literature. As a result, multiple studies recommend BPMN as a capable modelling tool. And by consequence, a large research project delivers expanded BPMN for modelling this business process. However, several studies show modelers how to specify IoT behaviour within business processes and at the same degree of abstraction using only normal BPMN.

The quantity of papers has been drastically decreased thanks to filtering. In fact, we have maintained the papers that suggest modelling IoT devices within business processes, including extended and non-extended BPMN, whether it is primary or secondary contribution, after the paper collection. As a result, we kept roughly 20 papers for a more thorough evaluation in our SLR. The BPMN language was used to model the major steps of the paper extraction and filtering procedures in Figure 5.

### **3.3 Defining Criteria for Evaluation and Comparison**

We set the following criteria to evaluate and compare research on the integration of IoT devices or smart technologies in business process modelling and in the specific domain of logistics and supply chain with the usage of BPMN:

- Publication type: If the extension has been published in a journal, a conference/workshop proceeding, or a book chapter, it will be indicated.



**Figure 5** Process of paper extraction.

Category: presenting an IoT device or in general such as ubiquitous systems field.

- Extension: authors are proposing any extension for modelling this specific domain
- Version: It specifies the BPMN language's expanded version (e.g. 1.2, 2.0, 2.0.2)
- Main domain: it designates if the proposed extension knowing applied to a specific domain.
- Modelling methods: IoT element, Process pattern, Metamodel or a Schema.
- Modelling tools: SC Signavio, GmbH Signavio Coor and other editor.
- Execution: either the proposed business process has been executed or not.

The final step involves presenting, interpreting, and analysing the results produced after a thorough evaluation of each document. To accomplish so, we start by categorizing, analysing, and evaluating all BPMN extensions for smart technologies domains in tables based on the criteria established in the previous paragraph. Then, using graphs such as pie charts and histograms, we present some data. Finally, we evaluate the findings and offer interpretations. Finally, by comparing the results to the previous ones, we can see whether there are any trends in BPMN extensions. To collect trustworthy and useful data, we focus on highly targeted domains by modelling IoT behaviours within business processes using BPMN.

## 4 Results

Domains involving physical entity interconnection are likewise extremely focused, as they have become very popular in recent years. They have several

distinct characteristics that must be taken into account, including energy consumption limits, limited resources, data transport [34].

The IoT and Ubiquitous systems sectors, for example, have been grouped together because they both require the connecting of physical elements via a network [33]. In the current circumstances, most corporate activities, particularly logistics and industrial production, have undergone a digital transition.

As a result, we discover Business Process Management Systems (BPMSs) that can provide highly integrated platforms for managing IoT systems' complete entities and activities. In IoT applications such as smart production business processes, BPMSs also provide self-managed behaviour.

In this context Table 1 shows a selection of 20 papers representing a minimum viable number to illustrate the current state of research for the specific research question which is modelling IoT integration using BPMN. The publications have been chosen for this means of significance of the contribution, number of citations, and actuality. And obviously responding to all criteria of evaluation mentioned in the previous section.

Table 1 represents the distribution of the use of BPMN by publication type and if they propose extensions for BPMN or not, respectively. In contrast, we notice that extensions for our topic domain are published in Journals. We can explain this by creating a model for this specific area. BPMN has many components, some of which may be ideal for constitutive thing integration. In any case, full analysis and a comprehensive solution to the problem are still lacking for the research community and modelling users, both conceptually and as a standard addition.

Nonetheless, the suggested BPMN Extensions are consistent enough in terms of contribution to be used in this field explicitly. However, we see a slowdown when executing the processes modelled by those extensions. None of the planned extensions were yet integrated into the current tools. As a result, its application in the workplace is not evident. Because BPMN is a relatively new language, there is a level of maturity in this research area (standardized by the OMG in 2006).

On the other hand, integrating smart technologies in business processes, especially in logistics, Supply chain and value chain management are becoming increasingly important. Some researchers are interested in the processes of a specific IoT application field, while others want to improve the BPMN language by proposing extensions to represent IoT specificities. Figure 6 compares the authors' contributions based on whether or not they propose BPMN enhancements.

**Table 1** Comparison of publications about IoT and BPMN according to their name, extensions, and execution

Authors	Title	Type	Year	Category	Modelling	Extension	Domain Version	Modelling of Application	Modelling Methods	Process Tools	Execution
			2019	COPD	BPMN	No	2.0	Healthcare	IoT element	/	No
Faruk Hasi and Estefan Serral Asensio [1]	Executing IoT Processes in BPMN 2.0: Current Support and Remaining Challenges	C	2019	COPD	BPMN	No	2.0	Healthcare	IoT element	/	No
Francisco Martins, Dulce domingos [16]	Modelling IoT behaviour within BPMN Business Processes	J	2017	General iot device	BPMN	No	2.0	/	Callas	/	JBPMN
Alaeddine Yousfi, Marcin Hewelt, Christine Bauer and Mathias Weske [21]	Towards uBPMN-Based Patterns for Modelling Ubiquitous Business Processes	J	2017	Ubicomp features	BPMN	Yes	2.0	/	Patterns	/	No
Francisco Martins, Dulce domingos [18]	Using BPMN to model Internet of Things behaviour within business process	J	2017	IoT	BPMN	No	2.0	IoT-aware business process	Callas	/	JBPMN
Roland Petrasch, Roman Hentschke [19]	Process Modeling for Industry 4.0 Applications Towards an Industry 4.0 Process Modelling Language and Method	C	2016	General iot device	BPMN/UML	No	2.0	No	Smart manufacturing	Magic draw	No
Alaeddine Yousfi, Christine Bauer, Rajaa Saïdi, Anind K. Dey [20]	uBPMN: A BPMN extension for modelling ubiquitous business processes	J	2016	Ubicomp	BPMN	Yes	2.0	No	Metamodel	/	No
Tranquillini, S., Daniel, F., Kucherbaev, P. Casati [10]	Modelling, Enacting, and Integrating Custom Crowdsourcing Processes	J	2015	Crowdsourcing	BPMN	Yes	2.0	No	Metamodel	BPMN4 Crowd editor	No
Meyer, Ruppen, A & Hilty, L. [13]	The Things of the Internet of Things in BPMN	J	2015	IoT	BPMN	Yes	2.0	No	Metamodel	/	No

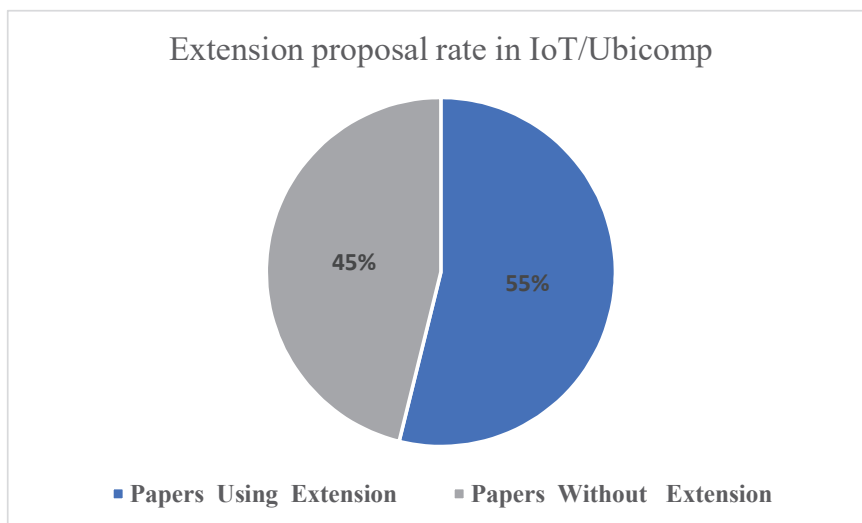
Ricardo Martinho, Dulce Domingos, [23]	Quality of Information and Access Cost of IoT Resources in BPMN Processes	J	2014	General iot device	BPMN	Yes	2.0	Quality of Information and Access Cost	/	No
Sungur, C. T., Spiess, P., Oertel, N., & Kopp [5]	Extending BPMN for Wireless Sensor Networks	C	2013	WSN	BPMN	Yes	2.0	WSN	Patterns	No
Sonja Meyer, Andreas Ruppen, and Carsten Magerkurth [17]	Internet of Things-Aware Process Modelling: Integrating IoT Devices as Business Process Resources	C	2013	General iot device	BPMN	Yes	2.0	NO	Business Process components	gmbh No
Appel, S., Kieber, P., Frischbier, S., Freudenreich, T., & Buchmann, A. [9]	Modelling and execution of event stream processing in business processes	J	2014	SPU	BPMN	Yes	2.0	0	Patterns	BPEL/ Software AG
Alexandru Caracuş and Thorsten Kramp [11]	On the Expressiveness of BPMN for Modelling Wireless Sensor Networks Applications	C	2011	WSN	BPMN	No extension	2.0	WSN	Patterns	No
Dar, K., Taherkordi, A., Baraki, H., Eliassen, F., & Geilbs, K [14]	A Resource Oriented Integration Architecture for the Internet of Things: A Business Process	Ch	2015	IoT	BPMN	No	2.0	Healthcare	XML	Activity BPMN Engine Android
Perspective Chiu, H.-H., & Wang, M.-S. [15]	Extending Event Elements of Business Process Model for Internet of Things	C	2015	IoT	BPMN	Yes	2.0	OCL	Patterns	No

(Continued)

Table 1 Continued

Authors	Title	Type	Year	Category	Modelling	Extension	Domain Version	Modelling of Application	Modelling Methods	Process Tools	Execution
Pedro Valderas, Victoria Torres, Estefania Serral [35]	Modelling and executing IoT-enhanced business processes through BPMN and microservices	J	2022	IoT	BPMN	No	2.0	Microservices	Patterns	/	Yes
Yusuf Kirikkayis, Florian Gallik, and Manfred Reichert [36]	Visual Decision Modeling in IoT-Aware Processes	C	2022	IoT	BPMN	Yes	2.0	/	Patterns	/	No
Faruk Hasić, Estefania Serral, Monique Snoeck [37]	Comparing BPMN to BPMN + DMN for IoT Process Modelling: A Case-Based Inquiry	Ch	2020	IoT	BPMN/DMN	No	2.0	/	Use cases	/	No
Romy Seiger, Romina Kühn, Mandy Korzetz, Uwe Abmann [38]	HoloFlows: modelling of processes for the Internet of Things in mixed reality	J	2021	IoT	BPMN	No	2.0	Holoflows	Patterns	/	No
Dulce Domingos, Ana Respício and Ricardo Martinho [39]	Reliability of IoT-Aware BPMN Healthcare Processes	C	2020	IoT	BPMN	Yes	2.0	Healthcar	metamode	/	No





**Figure 6** BPMN Extension proposal rate for IoT domain.

We note that most of the contributions support the use of BPMN extensions. While, when it comes to the execution of these processes, we find one from eight studies that had worked on execution.

The lack of how to execute those extensions, and the lack of modelling concepts to directly describe Internet objects as parts in a business process model is a key roadblock to successfully resolving and automating business processes in traditional BPM systems [16].

Table 1 acknowledges that most papers are not going through execution. Furthermore, the authors have not used smart technologies in our application domain which is supply chain.

#### 4.1 Evaluating Extensions

Most of the considered extensions are related to BPMN version 2.0. Extensions are mainly published in articles or chapters or as research which proves the compliance of the extension types proposed in the CPS/IoT/Ubicomp domains compared to other domains where they suggest extensions [3].

The main reason of proposing extensions is to delete the gap of modelling smart technologies with BPMN 2.0. But are those extensions still available for open use and handling by other modelling tools? Following that, we'll analyse the extensions in terms of their basic characteristics, BPMN standard

**Table 2** Comparison of publications about BPMN extensions for CPS/IoT/Ubicomp

Extension Name	Standard Conformity	Compliance	Semantic Conformity	Applied Method
Ubpnm [20]	✓			✓
Sungur BPMN4WSN [5]				✓
SPUs [9]				✓
Crowdsourcing [10]	✓	✓		
Things in BPMN [13]		✓		
Event Element for IoT [15]				
IoT representative [36]	✓	✓		
IoT devices as resources [17]	✓	✓		✓

compliance, and the extension technique or method that was used. The following criteria:

- **Standard conformity:** Extensions are defined through the BPMN extension system.
- **Compliance:** Extensions are defined using UML or OCL expressions in a dedicated meta-modelling technique. Alternatively, these extensions lack a meta-model and are simply defined by new notation components.
- **Semantic conformity:** every part of each meta-model should be checked due to resource limitations and since most of the articles were peer-reviewed before publication.
- **Applied Method:** applied the process model and extended the process model concerning a semantic equivalence check to ensure the necessity of extension.

Despite the quality of conformity shown in all research in this field. It doesn't allow us to use it fully while modelling processes in BPMN. Also, there is no evidence that any authors have extended a BPMN editor in practice in all of that literature. Except Authors [13] in their framework, have extended a web-based BPMN editor to include their IoT modelling elements as extensions to BPMN 2.0. The following Table 3 presents the different elements added in the BPMN as extensions for this notation.

In other fields such as healthcare, also many extensions have been proposed. The latest [24] offers a business process modelling extension with BPMN 2.0 to handle the IoT-aware applications and systems. The module allows for efficient data management in a fog/cloud federation context using data collected from IoT devices. Indeed, the suggested IoT-aware business process model considers physical entities, physical and virtual resources, IoT data, and QoS limitations, among other things.

Every proposed extension is supposed to cover most of the smart devices' models. While we found that one extension is not presenting a full package for modelling all needed activities for our specific domain of research which is IoT as shown in Table 3.

## **4.2 Modelling with Existing BPMN**

In both works of [7] and [11], modelling IoT behaviour has been done with the use of standard BPMN. However, IoT device data is contributed to the BPMN model in a non-standard fashion, such as by appending it to the pool name or by adding extra characteristics to the pool element. They convert BPMN, which describes IoT behaviour, into device-specific code. The authors claim that the sensor code they generate isn't considerably worse than handwritten code in terms of performance.

In [16, 18], at the same level of abstraction, the authors employ the standard BPMN language to model IoT activity within a business process. Following that, it explains how to convert BPMN IoT behaviour to Callas code, which can be deployed and executed in IoT devices.

The BPMN resource class, whose parameters are applied in queries at runtime for resource assignment, is used to specify the IoT devices that will perform processes. We also avoid incorporating non-standard information about IoT devices into BPMN models this way. Using simply standard BPMN, modelers may specify IoT behaviour within business processes and at the same level of abstraction.

Moreover, in [17], it was noted that in order to execute IoT processes, IoT devices must be coupled to process elements. The BPMN 2.0 standard provides a variety of ways for establishing this link.

Furthermore, the industry 4.0 process modelling method and the digital transformation that business models are familiar with make it possible to consider Industry 4.0 aspects such as IoT devices on a non-technical level for business process modelling by providing a modelling notation based on BPMN 2 [19].

Even for the WSN modelling case, where [5] and [8] are proposing a Framework of extended BPMN, we find [13] deeming that the BPMN language is expressive enough to specify behaviour at both higher and lower levels of abstraction for the set of WSN archetype applications.

From another perspective, in [22] the authors ensure that existing BPMS4IoT frameworks and IoT system models are compatible. The classification was done using their system architectures and deployment methods.



Crowdsourcing	Crowdsourcing is a way of outsourcing work to many people (a crowd). These are called crowdsourcing processes, which comprise of multiple tasks, actors and operations. These micro-tasks can be completed in parallel making it faster and efficient [10]	✓
Things in BPMN	This framework of Meyer models physical entity or the thing of IoT in a business process by extending BPMN. A IoT domain model defines the main IoT components that can be mapped with BPMN elements [13]	✓
Event Element for IoT	This work extends BPMN element event for business process modelling for IoT. As extensions to BPMN three event elements and one new modelling element representing location are introduced. The new events are conditional event, message event and error event [15]	✓
IoT devices as resources	An IoT reference model defines the main building blocks of IoT. They are the physical entity or thing, device (e.g. sensor), native service (e.g. sensing capability provided by the device's software) and IoT service (e.g. web service interface) [17]	✓

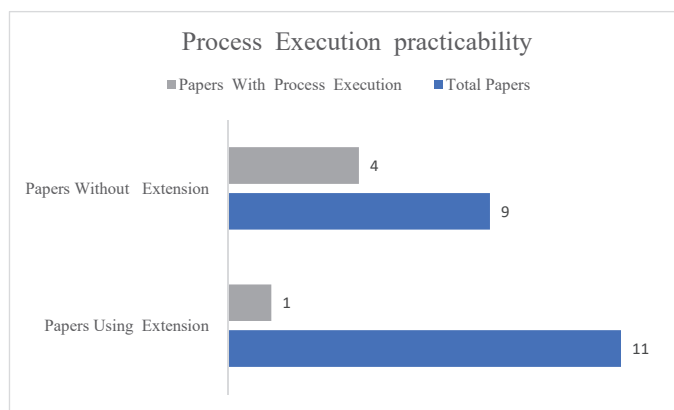
Mobile Cloud Computing (MCC), in the authors' opinion, is the key enabler of BPM for IOT. Thus, MCC disciplines can answer BPMS for IoT concerns, and it might be a potential approach to address issues and overcome challenges in this industry.

Moreover, in the recent research [35, 37] authors have used the standard BPMN combined with other design principles to model the IoT behaviour, such as Separation of Concern (SoC) and Decision Model and Notation (DMN). Hence, this approach of combining two different principles highlighted an important advantage of the ability to perform modular, explicit, and reusable context aggregations in the business process. In addition, the proposed approach supports the execution of this type as well of processes in such a way a great level of technology independence.

Still, as mentioned earlier in this work, the most real executed process cases are available for non-extended BPMN. As a result, we dedicated that, as others have modelled and implemented IoT behaviours in business processes, BPMN already provides the concepts to define the behaviour of various participants by using different pools, as well as the interaction between participants using collaboration diagrams.

### 4.3 IoT Execution Challenges

Even though the BPMN 2.0 standard already provides enough support for several areas of IoT process execution. In the following figure, we notice the most practical process execution for various activities had been done through standard BPMN.



**Figure 7** Process execution practicability in all references.

For a reason or another BPMN extensions remain important but not enough. As mentioned in [26], the BPMN standard does not provide any guidance, and only very few publications address developing new BPMN extensions. Thus, methodological, and domain-analysis aspects are investigated within the class “Method”.

For example, requirements analysis is seen as critical to the creation of artifacts. For redundancy and communication with domain experts, it could be reasonable to reuse existing domain artifacts. In order to justify the necessity for extension components, a discussion of the semantic fit with BPMN elements is also required.

## **5 Conclusion**

In recent years, business process modelling has emerged as one of the most important study fields, as it plays an important role in the creation of modern information systems [25]. Even though there are multiple languages for business process modelling, BPMN has risen to the top due to its expressiveness and simplicity.

Answering our research questions, we recognized that BPMN for modelling IoT-aware business processes result to be an interesting topic for business process and IoT community. However, during our study, we observed the lack of executing the proposed extensions from different type of works. In this regard, while analysing the various contributions, we synthesized an overview of the IoT requirements supported by standard BPMN. As a result, we can use it for modelling and executing different processes integrating smart technologies.

Furthermore, business process modelling is now required in plant simulations seeking to optimize resources and improve business processes virtually while calculating real-world effects prior to implementation. The trade-off between information quality and physical resource access cost must be considered in IoT-aware business operations [23].

The importance of modelling business processes in IoT using BPMN was highlighted in this survey. We collected all studies offering models with and without BPMN extensions, categorized them into distinct groups, and highlighted the need of process execution to conduct holistic IoT models in the logistics industry.

We analysed how well the latest BPMN standard enables IoT process execution. To deal with this, we have focused at existing research on the integration of IoT and processes and discovered that most of it revolves

around the modelling of IoT devices in processes with the use of BPMN. We believe that because most researchers use BPMN 2.0 for modelling, sticking to the standard's core is beneficial for IoT process execution as well. However, we identified some issues with IoT process configuration and execution using BPMN 2.0. Moreover, we analysed the literature to identify approaches that address these challenges.

The approaches offered in the literature, on the other hand, are either not standardized or insufficient to address the issues. As a result, we argue that these issues must be thoroughly addressed to acquire a clear picture of IoT process execution. In order to cement the integration of IoT and business processes for execution, the challenges outlined should be solved in the future. The burdens listed in the research challenges in this study will be addressed with special care. We'll focus on IoT resource binding for industries at runtime. We'll also study the changing patterns for IoT process evolution in real time in the different business processes of supply.

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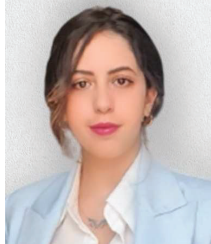


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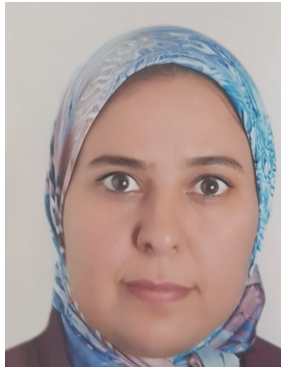


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