# The Internet-of-Things Meets Business Process Management: Mutual Benefits and Challenges

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**Abstract**

The Internet of Things (IoT) refers to a network of connected devices collecting and exchanging data over the Internet. These things can be artificial or natural, and interact as autonomous agents forming a complex system. In turn, Business Process Management (BPM) was established to analyze, discover, design, implement, execute, monitor and evolve collaborative business processes within and across organizations. While the IoT and BPM have been regarded as separate topics in research and practice, we strongly believe that the management of IoT applications will strongly benefit from BPM concepts, methods and technologies on the one hand; on the other one, the IoT poses challenges that will require enhancements and extensions of the current state-of-the-art in the BPM field. In this paper, we question to what extent these two paradigms can be combined and we discuss the emerging challenges.

**Keywords**

IoT (Internet-of-Things) — BPM (Business Process Management) — Challenges — Manifesto

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## Contents



## 1. Introduction

Our world is increasingly linked through a large number of connected devices, typically embedded in electrical / electronical components and equipped with sensors and actuators, that enabling sensing, (re-)acting, collecting and exchange data via various communication networks including the Internet: the Internet of Things (IoT). As such, it enables continuous monitoring of phenomena based on sensing devices (wearable devices, beacons, smartphones, machine sensors, etc.) as well as analytics opportunities in smart environments (smart homes, connected cars, smart logistics, Industry 4.0, etc.) and the possibility to actuate feedback. Therefore, the IoT contributes to the recent trend known as big data, being one of the three main sources besides human sourced and process mediated data.

Business processes represent a specific ordering of tasks and activities across time and place to serve a business goal. Process analytics, execution and monitoring based on IoT data can enable an even more comprehensive view of processes and realize unused potential for process optimization. As an example, in the past process analytics and in particular process mining has been hampered by the fact that process are often incomplete or erroneous; with the IoT producing a large amount of data stored in the cloud, even more data become available for analysis, possibly resolving issues of incompleteness and enabling providing error correction methods based on multiple data items [4].

In the literature, several works are emerging on combining Business Process Management (BPM) and IoT, e.g., utilizing sensor data to enable the actuation of services [15] or adapting running business processes to continuously align them with the state of the things (e.g., assets, humans, and machines). Still, there are many open challenges to be tackled (cf. Figure 1). Both BPM and IoT will benefit from a wider integration.

**How IoT can benefit from BPM?** Let us consider a complex system with multiple components interacting within a smart environment being aware of the components' locations, movements, and interactions. Such a system can be a smart factory with autonomous robots, a retirement home with connected residents, or, at a larger scale, a smart city. While the parties in the system can track the movements of each component and also relate multiple components' behaviors to each other, they do not know the components' agendas. Often their interactions are based on habits, i.e., routine low-level processes, which represent recurring tasks. Some of these routines are more time and cost critical than others, some may be dangerous or endanger others, and some may just be inefficient or superfluous. Knowing their agendas, their goals, and their procedures can enable a better basis for planning, execution, and safety.

**How BPM can benefit from IoT?** Let us consider a complex process with multiple parties interacting in the context of a business transaction. Such a process can be, for example, a procurement process, where goods are ordered, delivered, stored, and paid for. While the system can track each automatically executed activity on its own, it relies on messages from other parties and manually entered data in the case of manual activities. If this data is not entered or entered incorrectly, discrepancies between the *digital* (i.e., computerized representation of the) process and the real-world execution of the process occur. Similar concerns hold if the process participants do not obey the digital process under certain circumstances, e.g., an emergency in healthcare, or have not entered the data yet though in the real-world process the respective activity was already executed.

Such scenarios might be better manageable when closely linking the digital process with the physical world as enabled by the integration of IoT and BPM; e.g., the completion of manual activities can be made observable through usage of appropriate sensors. IoT can complete BPM with continuous data sensing and physical actuation for improved decision making. Decisions in processes require relevant information as basis for making meaningful decisions. In general, it is not sufficient to retrieve this data solely from traditional repositories (e.g., databases and data warehouse) providing historical data, but also up-to-date data are needed. Data from the IoT, such as events, provided through in-memory databases or complex event processing can be useful in this context. The IoT could reduce the need to manually signify the completion of manual tasks since sensor data is already available, leading to more accurate data, reduced errors, and efficiency gains.

To ensure that both domains can mutually benefit from each other, still exist several challenges to be tackled. Particularly, it has to be understood:

- how processes can improve the IoT by *(i)* taking a process-oriented perspective and considering the process history to *(ii)* bridge the abstraction gap between raw sensor data and higher level knowledge extracted from this event data, and to *(iii)* optimize the decision-making in the large;
- how to exploit IoT for BPM by *(i)* considering sensor data for automatically detecting the start and end of activities, *(ii)* using event data for making decisions in a pre-defined process model, and *(iii)* detecting discrepancies between the pre-defined model and actual enactment using event data for online process compliance checking and exception management.

In the following of this paper[1], taking these two general questions as starting point, we discuss IoT and BPM backgrounds in Section 2. Then in in Section 3, we detail the key challenges in combining BPM and IoT and elaborate on benefits of BPM for IoT and IoT for BPM, before offering concluding remarks in Section 4.

## 2. Background

### 2.1 Introduction to the Internet of Things

The Internet of Things (IoT) [3, 12] is the inter-networking of physical objects (the *things*), being such things embedded systems with electronics hardware, software, sensors, actuators, and network connectivity. Such connected things collect and exchange data. Each thing is uniquely identifiable through its embedded computing system and is able to interoperate within the existing network infrastructure. While things act local, the IoT allows things to be controlled remotely across existing network infrastructures, including the Internet.

[1]This paper has its roots in the Dagstuhl Seminar 16191 *Fresh Approaches to Business Process Modeling*, organized by Richard Hull, Agnes Koschmider, Hajo A. Reijers, and William Wong at the Leibniz Center for Informatics in Germany, May 8–13, 2016, cf. `http://drops.dagstuhl.de/opus/volltexte/2016/6696/`, to which many authors participated.

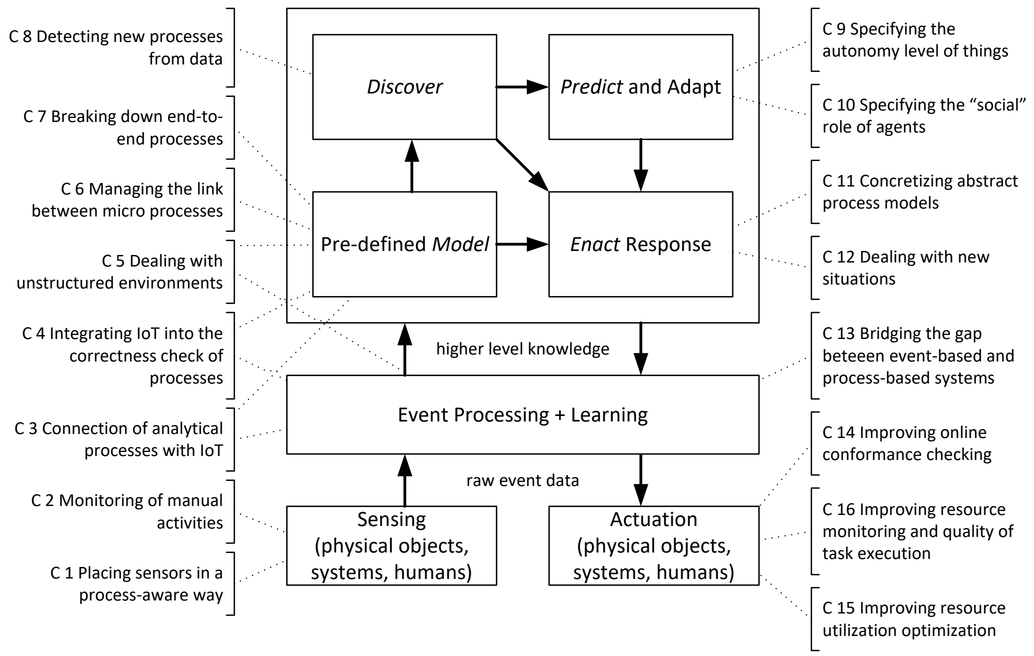


**Figure 1.** High-level overview showing the interaction between IoT and BPM. The numbering used in the blocks will correspond to the numbering of the different paragraphs in the following sections.

The interconnection of these smart objects/things is expected to usher in automation in nearly all fields. This creates opportunities for more direct integration of the physical world into computer-based and digitized systems, and results in improved efficiency, accuracy, and economic benefits besides increased automation and reduced human intervention. Experts estimate that the IoT will consist of about 30 billion objects by 2020 [22].

### 2.2 Introduction to Business Process Management

Business Process Management is a well-established discipline that deals with the identification, discovery, analysis, (re-)design, implementation, execution, monitoring, and evolution of business processes [7]. A business process is a collection of related events, activities, and decisions that involve a number of actors and resources and that collectively lead to an outcome that is of value for an organization or a customer. [7]. Examples of business processes include order-to-cash, procure-to-pay, application-to-approval, claim-to-settlement, or fault-to-resolution. To support business processes at an operational level, a BPM system (BPMS) can be used [27]. As opposed to data- or function-centered information systems, a BPMS separates process logic from application code and, thus, provides an additional architectural layer. Typically, a BPMS provides generic services necessary for operational, software-enabled business process support, i.e., for process modeling, process execution, process monitoring, and user interaction (e.g., worklist management). When using a BPMS, software-enabled business processes are designed in a top-down manner, i.e., process logic is explicitly described in terms of a process model providing the schema for process execution. The BPMS is responsible for instantiating new process instances, for controlling their execution based on the process model, and for completing them. The progress of a process instance is typically monitored and traces of execution are stored in an event log and can be used for process mining [32], e.g., the discovery of a process model from the event log or for checking the compliance of the log with a given process model.

So far, the predominant paradigm to develop operational support for business processes has been based on the *Model-Enact* paradigm, where the business process has been depicted as a (graphical) process model, which then could be executed by a BPMS. This largely follows a top-down approach and is based on the idea of a central orchestrator that controls the execution of the business process, its data, and its resources. With the emergence of IoT, the existing Model-Enact paradigm is challenged by the *Discover-Predict* paradigm; it can be characterized as a bottom-up approach where data is generated from physical devices sensing their environment and producing raw events. Sensor data then must be aggregated and interpreted in order to detect activities that can be used as input for process mining algorithms supporting decision-making [32].

## 3. Challenges

This section describes the challenges of interaction between the IoT and the BPM paradigm.

### 3.1 Overview of Challenges

The IoT has to deal with a number of challenges; this includes, for example, technological barriers such as computational limitations of embedded systems or the connectivity to back-end systems, security-related issues, a lack of standards, data privacy issues, untapped potential in data analytics, efficient methods for the organization of IoT systems, etc. [11]. The principal characteristic of the IoT is the communication between loosely-coupled objects, which mostly is accomplished asynchronously and ad-hoc.

BPM deals with the discovery of models, the analysis of pre-defined models, the adaptation of models, and the enactment of business processes. We consider processes as explicit process representations (pre-defined models), which later are enacted. Abstract processes can also be discovered from log files and suitable implementations for instantiation can be predicted.

Accordingly, sensing and perception via sensors and decision based on sensors as well as decision based on actuation according to individual goals/strategies constitute fundamental tasks of the IoT. Thereby, sensing constitutes the input and actuation the output of any IoT-BPM interaction (see also Figure 1). In between, raw event data is processed by event-based systems, transforming the input events to higher-level knowledge. In turn, the latter may be utilized by BPM concepts, methods or technologies to deal with the discovery of a model, the analysis of a pre-defined model, the adaptation of a model and the enactment of business processes.

While the IoT generally focuses on communication and data flow, BPM approaches consider control flow, big monolithic process models, and synchronous interactions. In addition, most BPM approaches have trouble dealing with non-routine, non-deterministic processes, whereas IoT applications typically involve these kind of interactions.

Against these considerations, plenty of challenges arise, which need be considered when improving business interactions as well as alignment between BPM and IoT. In the following we introduce each challenge in detail.

### 3.2 Challenges in Detail

**C 1 – Placing sensors in a process-aware way.** In order to collect all relevant data, sensors need to be carefully placed. It constitutes already a challenge to construct sensors and place them on agents (human or artificial) or in a smart spaces, such that they are non-intrusive but still efficient: sensors can be battery-less tags such as RFID, battery and renewable energy powered, or outlet-powered; and the communication methods can be wired or wireless. It is even more challenging to decide on the type of sensor and its placement with regard to its function in respect to the interaction between agents [30]. A business process (model) may guide this placement since it offers knowledge about resources, locations and variants of behavior (enact), that need to be covered. As well, the trade-off between the cost of introducing additional sensing points and the expected increase in monitoring accuracy may be approached based on process knowledge.

**C 2 – Visualization support for managing manually executed, physical processes.** In many settings, BPM approaches are used to automate processes through the support of a BPMS, in which some activities require the interplay between human operators and software/hardware modules. Notable examples, in addition to logistic and industrial processes, include disaster management (e.g., a BPMS in the field to coordinate emergency teams [5]) and healthcare processes (e.g., [25], or [6] – a BPMS coordinating doctors and nurses with vocal interfaces for human tasks). In many of these scenario, there is an increasing use of mobile devices fostering the delivery of work items to the right users [26].

In these settings, workers do not necessarily have to interact with the BPMS while carrying out physical tasks (e.g., moving boxes in a warehouse): sensors, which are connected to the BPMS, monitor whether or not such a task has started or ended. However, appropriate mapping from process activities to the GUI and usable visualizations are needed allowing actors (process participants) to perform their work in a natural way, without requiring non-value adding management tasks such as clicking on confirmation buttons.

**C 3 – Connection of analytical processes with IoT.** During process execution, a variety of information is required to make meaningful decisions. In turn, this information often needs to be available not only from traditional databases/data warehouses providing historical data, but it needs to be up-to-date and current. In order to design systems providing such up-to-date information, and to judge the quality of the data analysis results from such applications, it needs to be clear where the data stems from and where it has been used (*data provenance*), as well as the overall *quality* of the data at-hand needs to be ensured. This is particularly critical at the presence of big data [9]. Generally, it becomes necessary to find a way to annotate the data's origin and use this (meta-)information in process models. So far, there is no universal method to connect the analytic processes of observation, analysis, and decision-making to business processes in a standardized way, [14]; recent attempts include the Decision Model and Notation (DMN)[2] standard. Its focus, however, is on decision requirements, but less on the origin and use of decision data. Hence, it still needs to be investigated how to model quality and provenance in order to be exploitable at the process model level.

Erroneous sensors, not working at all or delivering erroneous data, need to be discovered and excluded from any analysis. In turn, this necessitates a reasonable judgment on which sensor data might be erroneous. Here, the process context in which these data occur might be helpful to identify erroneous sensors as well as to cope with them.

**C 4 – Integrating the IoT with process correctness checks.** Well-known techniques for analyzing the quality of process models can contribute to improve the design of interactions in IoT, by finding deadlocks, livelocks, or dead activities in respect to the behavior or interactions of objects [7]. Deadlocks and livelocks are reasons why some processes may not terminate in the assumed time frame or not at all. It can either occur because certain actions are waiting for each other or when actions change states but the process does not progress. While a rollback is a typical service in data management, it

[2] Cf. `http://www.omg.org/spec/DMN/1.1/`

becomes much more costly and complicated when managing processes and thus should be avoided. Dead activities do not harm a processes execution (unless they are supposed to be mandatory) since they will never be triggered. Yet, they represent a waste of resources as either or both, physical and/or virtual resources may have been reserved for this activity.

Therefore, designing correct process models which specifically consider the IoT nature of some components becomes crucial, as well as the verification of important properties.

**C 5 – Dealing with unstructured environments.** BPM offers a way to structure businesses. As such, it often assumes a controlled environment with a managed repository of versioned processes that can be orchestrated for the purpose of a single enterprise or be choreographed between parties in case of cross-organizational collaborations. Orchestration denominates the execution order of the interactions from the perspective and under control of a single party, whereas choreography describes public, i.e., globally visible, message exchanges, interaction rules and agreements made among multiple parties. Both concepts presume knowledge about the structure and/or interactions of each participating process. It is questionable whether orchestration and choreography still suffice as organizational concepts in an IoT world, which is much more ad hoc and situative (e.g., devices involved in the interaction might fail, deliver erroneous data, new devices may have to be flexibly added, etc.).

**C 6 – Managing the links between micro processes.** One approach to bridge the gap between IoT data and processes, would be to break end-to-end process models into micro processes representing habits and arrange them in a less prescriptive (control-flow) way. Modeling a small and possibly autonomous micro process does not necessarily require new modeling constructs or methods. Yet, the organization of hundreds/thousands of loosely coupled small processes is a task that cannot be left to the forces of natural evolution in a business environment. It may require new modeling constructs and methods to structure and represent their non-hierarchical interaction in human-readable form [21].

Data-centric process paradigms offer promising perspectives in this context. For example, object-aware processes [19] describe the behavior of single objects through micro processes, whereas the dynamic construction of linked objects as well as the their synchronized execution is described and enforced through macro processes. However, respective approaches need to be enhanced to integrate physical objects as well as their behavior in the overall process.

**C 7 – Breaking down end-to-end processes.** For a large class of processes (typically referred to as dynamic or knowledge-intensive), the advent of overwhelming sensor data and things acting in the environment without central control but according to "personal" agendas, makes it practically impossible to define comprehensive end-to-end process models. Things will perform their own routines, so called repeated behaviour patterns or habits [18] [13]. Accordingly, processes will have to be organized as *event-driven micro processes* to represent these habits. Whereas the overall end-to-end business process itself may be modeled in traditional ways, the linking of micro-process models is far more complex; to cope with this emerging complexity, the possible interactions between micro-process models must not be described at the low level of message exchanges, but be put at a higher semantical level, similar to the utilization of semantic object relations for the purpose of object interactions in object-aware process management.

**C 8 – Detecting new processes from data.** Designing a system in a bottom-up manner without prescriptive process models promises more flexible and inclusive processes. However, the question arises to what extent we can let the system just evolve and be discovered. When developing support for software-enabled business processes based on the principles of the IoT, an evolutionary self-organising process will take place in some respect. Thus, one must find the appropriate level of structuring and prescription without harming the capability to self-organize. There is a gap between IoT data and concepts at a model level to enable behavior prediction and to identify changes in behavior. The IoT allows deriving situational knowledge when tracking and evaluating data streams. Situational knowledge, in turn, is input to analyze prospective knowledge, which constitutes a dynamic task. Prospective knowledge addresses long-tail information about resources (e.g., how well is the person/thing doing? Are there any behavior changes expected?). Moreover, data streams from sensors need to be tracked, mapped to information entities, and simulated. Additionally, the output (goal) must be known (e.g., save time, save costs, improve health) and its derivation as well as the reconciliation of private goals must be mapped with organizational goals, which in turn is a challenge of the IoT. An alignment between event-based and process-oriented systems indispensable in this context[3]. A starting point could be to define goal-based deviation patterns and to provide modeling techniques considering sensor-data and event data.

**C 9 – Specifying the autonomy level of IoT things.** Objects in the IoT are able to react to events by executing tasks or entire processes. The execution of the latter is typically asynchronous and sometimes not explicitly started from a central coordinator. The execution of tasks or processes may further trigger certain reactions, for example the start of another process to correct deviating behavior. Yet, it is unfeasible to grant things full autonomy to decide everything without supervision. Hence, there has to be a concept of autonomy levels that dictate if things need supervision and may be vetoed, be it an individual or a group. Currently, there is no universal way to talk about these levels of autonomy or to resolve conflicts originating from this distinction [23, 29]. While different conceptualizations of individual and group autonomy exist, they have not been transferred to BPM yet. Moreover, there is a lack of understanding on how to express them in a business

[3]Alignments between both system types were discussed at a Dagstuhl seminar `http://www.dagstuhl.de/de/programm/kalender/semhp/?semnr=16341`.

process model, e.g. using patterns or further attributes.

**C 10 – Specifying the "social" roles of agents.** Organizations aim to optimize their business processes based on organizational (i.e., group) goals. However, process participants often follow personal, i.e., individual processes or agendas with individual goals. The challenge is to synchronize/ reconcile different, possibly conflicting goals. These agendas are typically mitigated through governance processes prescribing desired behavior. The individual goals of a thing are typically not precisely known or explicitly given. Furthermore, these processes may be less prescriptive micro processes or habits. Hence, holistic and prescritive governance may not be possible. Hence, it is an option to define and specify social behavior of things (such as self-interest, helpful, cooperative [17]) to better coordinate and govern their behavior. This becomes even more challenging, when also considering robotics, i.e., the integration of human actors as well as robots in processes (raising issues like exchangeability, co-existence of different kinds of resources etc.).

**C 11 – Concretizing abstract process models.** Abstract process models are sometimes used to model processes at design time without providing the details necessary for execution. This is a sensible approach when dealing with very dynamic scenarios. In these cases, it is possible to define the process but the abstract model has to be turned into a concrete model later before being executable, for example by discovering available services as well as the conditions in which these services may be used. Context also includes physical data about users, e.g., location, devices the user carries with him (e.g., smartphone), etc. For the discovery phase (see Figure 1), the semantics related to the services (i.e., what functionality can the service offer specially within the context of the process) should be available and it should be possible to reason over this for matchmaking purposes. In addition, the services' discovery phase may lead to changes in the schema of the original abstract process. Examples of corresponding changes include the skipping of certain tasks initially planned in the process or the addition of new fragments (e.g., combining two or more services either in sequence or parallel to achieve the task goal). Despite all flexibility, this phase of instantiation presumes a given structure in form of the abstract process model.

**C 12 – Dealing with new situations** Individual ad hoc decisions may resolve a current situation from an individual's or a small group's point of view towards favorable results for them. In a complex business environment, foresightful and structured decision making cannot only achieve similar results but also save costs and time, and possibly improve the total quality. Deterministic event detection and correlation can be very well modeled and executed with event processing languages in complex event processing engines. However, the flexible discovery of new situations and the derivation of new responses constitute major technological challenges whose tackling can benefit from the combination with BPM.

BPM methodologies and technologies can support the identification and selection of appropriate responses by recommending tasks, triggering tasks or whole processes, and automating as well as monitoring their execution. These reactions can be pre-defined using existing BPM technologies and learning can be based on the analysis of historic traces to identify beneficial habits from a higher level perspective. Furthermore, reference models can help to identify state-of-the-art industry blueprints, which can be contextualized and instantiated to find a proper reaction for the context and the history of the situation. The capability of IoT sensing can be of additional benefit here.

**C 13 – Bridging the gap between event-based and process-based systems.** A challenge is to bridge the gap between clouds of sensor data and event logs for process mining. Events captured by sensors are available in high volume, velocity, and variety. They are often affected by noise and errors. Process knowledge can be employed to support the identification of events from raw event data and in a subsequent step entire processes including their activities from event data. This is a non-trivial problem since event data belonging to different activities can be interleaving. Moreover, event data can belong to or be relevant for several activities, so that complex n:m relations between events and activities have to be considered. The question of mapping start and end of event (streams) to the start and end of a process is closely related. Once the activities have been discovered, the next challenge is to discover the corresponding processes, i.e., to correlate the activities with the corresponding process instances. Process knowledge and BPM methodologies can support the discovery of these habits, the identification of their underlying interactions as processes as well as the optimization of these habits to reduce the waste of time and resources and increase the safety of all involved agents. Process mining techniques provide promising ex post perspectives in this respect, but require the presence of an event log that organizes the events in terms of traces representing the execution of a process instance [32]. Similarly, but in an on-line fashion, complex event processing can be used to derive higher level knowledge from raw events to provide an ex nunc perspective [15]. Here, the timely provisioning of events is crucial.

**C 14 – Improving online conformance checking.** As detailed earlier, conformance checking is a process mining technique that compares an existing process model with an event log of the same process. It can be used to check if the reality of process execution, as recorded in the log, conforms to the model and vice versa. Online conformance checking takes as input the context data and performs the comparison online. This requires high quality data and almost complete information. Again, the IoT as a data source and data management technology can play a major role and might improve the conformance checking of the actual physical execution with the execution order as recorded by the BPMS based on a secondary log of sensor data. Similarly, the checking and monitoring of compliance rules to be obeyed during process execution might benefit from IoT data sources and data management technologies.

**C 15 – Improving resource utilization optimization.** BPM can provide a governance structure for an organization, be it physical or virtual. BPM initiatives break up traditional functional silos and introduce process managers being responsible for processes across departments. While complex systems and the IoT is centered around situations to react to, BPM initiatives are organized around processes. This entails that some coordination instance responsible for priorities and resource provisioning can monitor and intervene with additional knowledge if necessary. In a pure IoT paradigm, there is the danger that decision will only produce local optima. Research has shown, for example, that situational decisions about resource provisioning as it is common in virtualized environments, e.g., CPU usage, can be optimized from a process perspective through BPM knowledge when executing known procedures or behavior patterns [8, 16]. Vice versa, research has also shown that process knowledge can optimize event processing [33]. The coordinating unit responsible for resource provisioning has advanced knowledge about the future behavior of agents since they have to follow their process models and, thus, can provide resources (e.g., computing power, network bandwidth, or things) with greater accuracy reducing processing time and thus increasing the throughput of a process. It also helps to reduce communication time-outs and thus, rollbacks, or abnormal process terminations.

**C 16 – Improving resource monitoring and quality of task execution.** The execution of tasks in a business process consumes resources. These can be IT, such as storage capacity for process data, computing power for calculations in scientific workflows, artificial agents, such as as robots automatically executing manual tasks, or human beings entering or analyzing data or performing manual tasks. Also machines, e.g., packing drugs, can be considered as resources (e.g., predictive monitoring, i.e., when does the machine have to be maintained taking its usage as well as historical data into account).

All these resources migth suffer from issues, which hinder optimal working conditions such as over- or under-utilization or even damage/ illness. IoT-based sensors can pick up these issues by measuring machine-behavior or human stress levels [1] and suggest changes to process execution to alleviate these effects. Furthermore, the IoT can support the execution of (knowledge-intensive) tasks in a process through context-specific knowledge provisioning, e.g., in terms of instructions or training materials on how to execute the task, or regulations that are relevant for the user's particular context. Sensor data can be leveraged to determine the actual context [10] and to identify information needs (e.g., detection of cognitive overload or stress).

## 4. Concluding remarks

The IoT provides many opportunities for industry as well as for personal use through the meaningful, yet dynamic interaction of humans, software, machines, and things. BPM is a well established discipline that deals with the discovery, analysis, (re-)design, implementation, execution, monitoring, controlling and evolution of business processes.

So far, both areas have been considered separately. In this paper[4] we have formulated a number of challenges for the amalgamation of the IoT and BPM, which we deem important to be tackled in the near future in order for the IoT to benefit from business processes and vice-versa.

Before concluding, we would like to highlight a cross-issue, i.e., dealing with security and, in particular, privacy issues. For example, privacy levels that exist at the sensors level might be different with respect to those at the BPM side. A full-disclosure approach should be avoided, especially in contexts where sensitive (i.e., personal) information is collected. The most relevant challenge, in this case, is the communication between the two worlds, each of them with corresponding privacy/security levels and policies. The layer in charge of integrating these two sides should be designed according to the principles of privacy by design [20]: "identify and examine possible data protection problems when designing new technology and to incorporate privacy protection into the overall design, instead of having to come up with laborious and time-consuming "patches" later on" [28]. This issues can also be seen as a "non-functional requirement" referring to C1, C3, C4, C6, C8, C13, and C14, but also other challenges might be affected. Fibally, partially related to the previous point, are ethical aspects of the integration of IoT and BPM: the introduction of raw events paves the way to a whole new set of analyses and explorations. On the one hand, these analyses must preserve the privacy of the individual (privacy is recognized as a fundamental right[5].). At the same time, the analyses should not be unfair and should not provide unequal treatment of people based on membership to a category or a minority. This problem is typically referred to as "discrimination-aware data mining" [24]. More generally, the literature also talks about "privacy-preserving data mining" [31, 2]. There are several challenges that are directly affected by that such as C2-C6 and C13-C15. This is due to the set of analyses that the integration of IoT and BPM will make possible.

[4]This paper is a living document. All persons willing to provide feedbacks and improvements are welcome to contact the authors.

[5]Cf. Article 8 of "European Convention on Human Rights" `http://www.echr.coe.int/Documents/Convention_ENG.pdf` and Article 12 of the "Universal Declaration of Human Rights" `http://www.ohchr.org/EN/UDHR/Documents/UDHR_Translations/eng.pdf`

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