Internet of Things Meets BPM: A Conceptual Integration Framework

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Abstract: Business process management (BPM) is considered as a powerful technology to design, control, and improve processes. Recently, organizations have started contemplating the value that combining the inter-networking of all kinds of physical devices, i.e., the Internet of Things (IoT) with BPM could bring to an organization. BPM provides intelligent control over IoT devices by integrating and managing devices and data generated by them in business operations. Here, data from IoT devices needs to be analyzed and actions need to be taken based on that data. Since the real world as context of a BPM application changes drastically through the advent of IoT, it is worthwhile to investigate how the enactment of a BPM application changes or must be customized. In this paper, we first describe benefits and necessary adaptions w.r.t. the integration of IoT and BPM systems. Furthermore, we tackle two concrete adaption tasks, i.e., we introduce concepts for IoT enhanced process modeling as well as a technological integration architecture. Both approaches have successfully been evaluated in production industry.

1 INTRODUCTION

Business process management (BPM) is considered as powerful technology to operate, control, design, document, and improve cooperative processes (Dumas et al., 2013). Processes are executed within application systems that are part of the real world involving humans, cooperative computer systems as well as physical objects. Internet of Things (IoT), denoting the inter-networking of all kinds of physical devices, has become very popular these days. IoT basically is a cyber-physical system digitally communicating over the internet. Devices developed nowadays, from any industry like healthcare, manufacturing, automobile, are equipped with a micro controller and capable of transmitting data over a network. Businesses need to overcome several challenges to be able to realize cooperative orchestration and manageability of such IoT devices (Al-Fuqaha et al., 2015). IoT has slowly started to penetrate markets as businesses and organizations have perceived the value that combining IoT with BPM could bring to an organization. The integration of IoT and BPM impacts critical business processes requiring integration with operational systems, from enterprise resource planning (ERP) and customer relationship management (CRM) to specialist applications. BPM uses process models to manage, update, and track large volumes of data and information generated by these smart devices (Dumas et al., 2013). Looking from an IoT viewpoint, BPM adds value to IoT (and vice versa) by providing intelligent control over IoT devices by integrating and managing devices and data generated by them in business operations. Embedding intelligence by way of real-time data gathering from devices and sensors and consuming them through BPM helps businesses to achieve cost savings and efficiency. Data from IoT devices needs to be analyzed and actions need to be taken based on that data. These actions trigger alerts or invoke corrective processes and activities before routine issues snowball into disasters, e.g., flight delays, parts replacements, fire emergencies. Since the real world as context of a BPM application changes drastically through the advent of IoT, it is worthwhile to investigate how the enactment of a BPM application changes or must be customized through the transition of the real world through IoT technology. This investigation leads to three fundamental research questions that are tackled in the course of this paper: (i) What can IoT provide in the interplay with BPM? How can BPM concretely benefit from IoT? How must a BPM system be adapted to the IoT world? Existing works in this area, e.g., (Petrasch and Hentschke, 2016; Petrasch and Hentschke, 2015; Graja et al., 2016; Meyer et al., 2013; Meyer et al., 2015), exclusively focus on extensions of standard process modelling languages for IoT and disregard all other phases of BPM as well as conceptual foundations. In this paper, we examine

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these open research questions in a systematic way: *(i)* we describe IoT characteristics and the interplay with BPM; *(ii)* we outline benefits and necessary adaptions w.r.t. the different phases of the BPM lifecycle (Dumas et al., 2013) which ultimately leads to a research agenda for the integration of IoT and BPM systems; and *(iii)* we introduce *generic* concepts and solutions for IoT enhanced process modeling.

This paper is structured as follows: Section 2 introduces characteristics of IoT applications and a classification of benefits and necessary adaptions. Section 3 gives an overview of related work. In Section 4 we describe concepts of IoT enhanced process model re-engineering. The introduced approaches are evaluated in Section 5. The paper is concluded in Section 6.

2 RESEARCH QUESTIONS

In this section, we first characterize IoT enhanced applications. Second, we describe the different anchors where IoT can influence BPM scenarios. Based on this, we outline further research questions in this context and classify them w.r.t. the different phases of the BPM lifecycle.

2.1 IoT Characteristics and BPM

First, we briefly highlight the most important characteristics of IoT applications (Al-Fuqaha et al., 2015): *Data intensive:* In IoT applications, the environment status changes regularly. Devices, sensors and humans frequently change their status, e.g., temperature, location or the current energy and send their status information and data at a regular rate to a gateway or server; *Pre-processing:* IoT applications depict a tremendous amount of data, often on a very low, unsuitable abstraction level. In many cases, data stemming from sensors have to be pre-processed for further enactment; *Triggering:* IoT use cases frequently imply real time triggering of activities based on current sensor data and defined alarm thresholds; *Ubiquitous:* In many IoT scenarios all kinds of physical devices as well as humans are connected through mobile devices such as wearables.

These four characteristics form the basis for the following discussion. When discussing BPM and IoT it is worth to principally investigate the interplay between these two concepts and prepend a conceptual discussion of this interplay before we investigate concrete enactment plans. We consider a BPM system as a sphere of control. Such a system reacts to factors, events, causes etc. that are either stemming from the system itself or stemming from the outside of this system. In system theory, the first type of factors is characterized as being *intrinsic* and the second as *extrinsic*. An example for an intrinsic factor for BPM is the internal state of an organizational database: there, available agents for process executions are listed. An extrinsic factor of a BPM application is the breakdown of power supply in a certain part of the application. This external event causes many resources not being available for process execution anymore.

From the viewpoint of a BPM system the IoT world is a source for extrinsic factors. The interaction between these two spheres of control can even be specified in more detail. In principal, there are two different communication channels between a BPM system an IoT: a *passive* and an *active* one. We can consider a database as implementation of a passive communication channel. For example, IoT devices produce data and store them into such a database (*cf. Data Provision*). The BPM system can eventually access them and incorporate them into its calculations. In that sense, data provision from the extrinsic system IoT extends the data reservoir of a BPM and can thus improve and/or extend its functionality. We regard things like events as a form of active communication: they are generated and sent to the communication partner to trigger some activities there (*cf. Triggering*). For example, an IoT device sends some event to a BPM system, which there causes the execution of a task. According to this, an active communication channel typically triggers things in the receiving sphere of control. By the way, these two kinds of interaction - active and passive - can also occur from a BPM system to an IoT system. For this paper the other direction of communication is more relevant.

After having introduced the general interplay between a BPM system and an IoT environment, it is interesting to zoom into this interplay, i.e., it is interesting to see how concretely this interaction can take place. For this reason, we introduce a general set of modelling elements for processes. A process is characterized by a couple of perspectives (Jablonski and Bussler, 1996). The *functional* perspective defines the body of a process step, in particular defines its name, purpose, etc. The *behavioral* perspective defines the control flow between process steps. Among other things, incoming events trigger starting of activities, outgoing events might function as triggers for other activities. The *organizational* perspective assigns (human) resources to process steps. The *operational* perspective assigns services and programs to activities. The *data* perspective defines input and output data for activities and thus establishes a data flow. The issue for characterizing the interplay between BPM and the IoT is to define how communication between these two spheres of control mutate the functionality of the mentioned five perspectives.

Since the functional perspective is just the skeleton of a process step, it will not be changed noticeably - but more indirectly via the other perspectives - by the IoT communication. However, all other perspectives will undergo positive modifications by this interplay. The data perspective will heavily profit by the enlarged database provided by IoT. Not just the range of data can drastically be enlarged, but also the accuracy and currentness of data will be improved broadly (cf. *Data intensive*). This can lead to a new quality of process execution and new ways of function provision. The latter leads to a direct improvement of the operational perspective of a process step. In addition, the organizational perspective of a process profits from data provided by IoT. For example, the actual geographical position of agents are reported by wearables such that agent assignment can consider this information and can better assign people to outstanding tasks (cf. *Ubiquitous*). The behavioral perspective mostly benefits from the active communication between IoT and a BPM system. For example, an IoT signal can promptly trigger starting an activity directly what can improve performance of process execution significantly (cf. *Triggering*).

2.2 How Can BPM Benefit from IoT?

This discussion of the interplay depicts how positively an IoT integration into a BPM system improves and enlarges its functionality. From a BPM system, the IoT world acts as an extrinsic factor that actively and/or passively affects the BPM system and enables new or enhanced functionality. In this section, we highlight the main benefits that IoT provides for BPM applications and classify them w.r.t. the different phases of the BPM lifecycle (Dumas et al., 2013).

Within the *modelling* phase of the BPM lifecycle, the incorporation of IoT technology can reduce the complexity of process models, i.e., it is possible to replace elements and patterns due to the opportunities of IoT. In particular, certain activities, e.g., manual control activities, can be avoided and thus removed from existing models. Furthermore, through the provision of a broad and highly up-to-date database, process models can be logically extended and enriched with new dimensions and new perspectives. For example, pure control-flow oriented models can be extended with data dependencies stemming from IoT devices. The location awareness of IoT devices like wearable computers creates the opportunity to introduce a locational perspective into process models and, for instance, assign activities to the staff members based on distance measures. These new features lead to more fine-grained and more specific process definitions that better reflect operational reality. Also the *execution* phase can benefit from the integration with IoT. Here, real time interaction, mobile and wearable interfaces for process control, new signaling as well as activity indication technology (e.g., haptic and acustic signals of smartwatches) can lead to significant latency and activity runtime reduction that ultimately leads to an improved overall case performance. Incorporating IoT technology fosters process *monitoring* as well. Here, data provided and provisioned by IoT sensors increases process transparency, e.g., the remaining time until next activities as well as certain important environmental data. Last but not least, IoT enhances the *analysis* phase by increasing the quality and evidence of process event logs by recording rich process data in form of IoT sensor and device values. This big amount of data enables and fosters multi-perspective process mining technology (e.g., (Sturm et al., 2017)) which automatically produces data enriched process models.

2.3 How Must BPM Be Adapted?

The discussion will show how a BPM system must be customized to be enabled for the interplay with IoT. We will again use the BPM lifecycle for classifying the adjustment tasks. We distinguish between necessary conceptual and technological adaptations. The different aspects are summarized in Table 1.

First, we focus on the *modelling* phase of the lifecycle where certain conceptual adaptations are necessary to incorporate IoT devices and sensors into process models. Here, it is potentially necessary to reengineer existing process models, i.e., activities need to be added, removed or rearranged, data objects reflecting IoT values need to be added and organisational dependencies redefined. These adaptations reflect the inclusion of new entities stemming from IoT technology. This re-engineering can even go to such lengths that the used modelling language is extended with new modelling elements to ensure understandability of models. In this paper, we will tackle this issue in Sec. 4. Furthermore, it is important to mention that IoT technology introduces new dimensions into BPM scenarios that have not been covered by existing languages yet and thus require semantical enrichment of languages. For instance, the assignment of activities to the closest staff member, i.e., a location dependent assignment condition can easily be implemented with IoT devices, however, is not covered in standard languages like BPMN. The *execution* phase requires several adjustments, both on a conceptual as well as

Table 1: Conceptual and technological adaptations to enable IoT/BPM integration.

Lifecycle Phase	Conceptual Adaptations	Technological Adaptations
Modelling	- (Re-)engineering of models - Modelling language extension - Semantical enrichment	
Execution	- Adjustment execution engine - Bridge abstraction gap between low-level sensor data and business activities	- Context variables - Layer architecture
Monitoring	- Presentation/Visualization of extrinsic and intrinsic data	- Layer architecture - Big Data visualization
Analysis	- Focus on data aware mining	- Big Data methods - Performance

on a technological level. Conceptually, it is necessary to adjust the underlying BPM execution principle and engine to be able to incorporate IoT related data into calculation of next actions. Technically, this can be achieved by defining certain context variables in a BPM system that hold specific values and current status of IoT devices. Furthermore, it is necessary to bridge the abstraction gap between low-level sensor data stemming from IoT devices and high-level business activities. While sensor data is frequently captured with a very high frequency, i.e., many data points are acquired, only a small number of observed sensor values are really relevant for business activities. For instance, corrective activities are only triggered if a sensor value is above a certain threshold. Thus, a tremendous amount of data, typically stemming from various IoT devices needs to be gathered, stored and processed. The solution to bridge this gap is a layered architecture that manages the whole abstraction and aggregation process, from the acquistion and processing of raw data towards the communication with a BPM system. Within the *monitoring* phase it is necessary to complement process execution cockpits and dashboards with suitable data presentation and visualization concepts to represent extrensic and intrinsic data of IoT devices to process participants. From a technical point of view, the monitoring of real time data of the IoT world is a severe challenge since storing and in particular visualizing a big amount of data requires specific big data methods. Smart data querying and visualization techniques need to be deployed in BPM system interfaces to ensure practical applicability and to prohibit performance issues. The *analysis* phase depicts the application of process mining on event logs. Traditional mining techniques have a strong focus on control-flow related dependencies while especially process relevant data is frequently neglected (van der Aalst, 2011). It is obvious that with the integration of IoT the analysis of process data becomes a first-class citizen in process analysis. Through data-aware process mining the automatic analysis of event logs yields process models with semantically enriched data dependencies. Thus, temporal dependencies and activity runtimes can be traced back to data values, locations and device status stemming from IoT devices. From a technological viewpoint, the incorporation of data into process mining will inevitably lead to performance issues and thus require the application of latest distributed big data analysis techniques for process discovery (Sturm et al., 2017). The discussion highlights that the integration of IoT and BPM requires deep conceptual and technological adjustments in each phase of the lifecycle. We claim that the content of Table 1 can be seen as a (for sure not complete) research agenda for establishing an effective interplay between IoT and BPM. In the next section, we show that existing work mainly focuses on modelling language extensions.

3 RELATED WORK

Several approaches have been proposed to connect the Internet of Things with business processes and to make use of real world objects data when executing business processes. In (Petrasch and Hentschke, 2016; Petrasch and Hentschke, 2015) the authors present the Internet-of-Things-Aware Process Modeling Method (IAPMM), a software oriented approach, that only covers the requirements analysis so that for design, implementation and test phases other methods have to be used. The method extends the BPMN 2.0 metamodel and consists of five steps, to detect and model the processes, namely: Functional Decomposition, identification of IoT aspects, creation of IoT-aware business process models, detailed specification of processes and data elements and consistency check of all models. The outcome is an IoT-aware business process modeled with the IoT-aware process model notation (IAPMN). The approach proposed in (Graja et al., 2016) (named BPMN4CPS) also describes an extension of the BPMN 2.0 metamodel, in which the process logic is split in three parts: the cyber part, the controller and the physical part. They are displayed as pools in the BPMN and have different activity types, which can be executed. Furthermore the authors extended the metamodel by new task types for Cyber-Physical Systems: the cyber task, the manual task and the physical task. Some more notation concepts in BPMN for IoT are described in (Meyer et al., 2013; Meyer et al., 2015; Sperner et al., 2011). The main focus is the definition and modeling of real world properties. In (Meyer et al., 2013; Meyer et al., 2015) the authors present an extension of BPMN with seven new modeling concepts (IoT Activity, Sensing Activity, Process Resources, Physical Entity, Real World Data Object/Store, Mobility Aspect and IoT Process Ratios). In (Domingos et al., 2014) an approach for implementing the problem in the WS-Business Process Execution Language (WS-BPEL) is introduced. It extends WS-BPEL by two constructs: context variables, which are automatically updated (synchronously or asynchronously) and the when then construct. The authors implemented and evaluated a prototype extension which is compliant with every WS-BPEL engine. The next steps would be to apply the concept on BPMN and evaluate it. Other approaches implementing WS-BPEL extensions with context variables are presented in (George, 2008) and (George and Ward, 2008). The variables are updated using the publish/subscribe paradigm following the WS-Notification standard. The extension was implemented by adjusting the ActiveBPEL 4.1 engine. In (Mateo et al., 2012) the authors integrate distributed resources into WS-BPEL by formalizing a fragment of WS-BPEL together with the WSRF (Web Services Resource Framework). In (Schmidt and Schief, 2010) the authors propose an approach for enabling IoT-based agile business processes. They implemented it by extending business process models by information on variance and triggers for variance. To integrate these extensions, two blind-spots had to be brightened, the environment and the actual process activities. The authors describe concepts, how to do those challenges in a system. A system to realize and evaluate the ideas is the ADiWa project.

4 PROCESS (RE-)ENGINEERING

The adaptation of BPM approaches already has to start in the modelling phase. In order to reflect the consequences of IoT involvement in BPM, existing process modeling languages and process models can and need to be remastered.

4.1 Language (Re-)Engineering

Recent research (Petrasch and Hentschke, 2016; Petrasch and Hentschke, 2015; Graja et al., 2016) suggests extensions regarding modelling notations as well as process execution languages. Since these extensions have already been presented in Sec. 3, we focus on a systematization of extension types. Existing conceptual process modeling languages have to be extended to cope with the requirements and the potential emerging due to the involvement of the IoT world. This comprises further discriminations regarding the different activity types to be able to represent IoT-supported activities. It is necessary to reconsider the capabilities for representing the operational aspect of processes. Yet, modelling elements related to this perspective are limited to semantics like ”what tool can be used”. With the involvement of IoT concepts it is additionally possible to shift the *responsibility* for the whole activity execution to the IoT. This cannot be represented with existing process modeling languages (Graja et al., 2016). In order to make IoT-enhanced models executable again, it is necessary to extend existing transformations from conceptual to executable models (Domingos et al., 2014).

4.2 Process Model (Re-)Engineering

We distinguish between model changes through partial replacement or substantial enrichment of model contents. In this section, we describe some exemplary manifestations for each type.

The examples for potential model changes are represented using an *abstract* process modeling language. We forgo using an existing graphical language because non of them is able to fully cope with all concepts we discuss later. However, the abstract language reuses well-known modelling elements from existing languages. Rectangles and circles represent an activity or an event from the BPMN 2.0 language, respectively. The activity *Act* in Fig. 1 (b) is IoT enabled, i.e., involves communication with IoT devices. All edges are defined in the graphical declarative notation *ConDec* (Pesic et al., 2007). This means, for instance, that *Manually observe* is the first activity in all process instances, it can be repeated and it has to be eventually followed by an event *Condition fulfilled*. We additionally use a diamond-shaped symbol to indicate data-based conditions that further restrict the execution of those activities it is connected with. We use circles with user symbols to denote roles and associated resources. Since we explicitly do *not* suggest a new process modeling language we omit a more detailed discussion of the modeling elements.

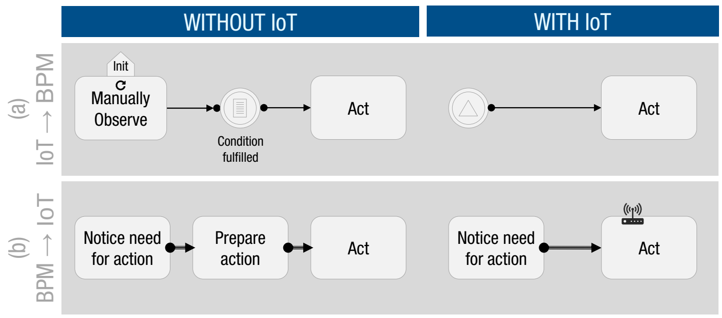

Figure 1: Example applications for the IoC principle.

Inversion of Control (IoT to BPM). One major difference that follows from the involvement of IoT in BPM systems is the opportunity to implement the *Inversion of Control (IoC)* principle. Coming from the software design discipline this principle describes guidelines for improving software modularity. In its core it states that the flow of interactions in a computer program is determined at runtime based on data objects and their interactions. Transfered to the topic of IoT-BPM integration this means the replacement of dedicated pull requests for information with push operations from the information provider. Due to the rich communication abilities of IoT devices they can act as such an provider. An abstract example for reflecting this change in a process model is visualized in Fig. 1 (a). Without involving the IoT these information can only be accessed actively. Following the IoC principle one can remove the representation of this manual access from the model and insert an incoming signal event element. This can be used to lay the focus on the information usage instead on its acquisition and *busy-waiting* activity can be eliminated.

Inversion of Control (BPM to IoT). Triggering IoT activities from BPM activities is relevant, too. In many cases, e.g. in the manufacturing industry, it is necessary to prepare certain activities. This can be, for instance, the physical movement to a machine that requires an user intervention. Due to the connectivity improvement provided by IoT it is often possible to eliminate this preparation step. The prepared activity element can then be replaced by the representation of an IoT-enabled activity. An example is shown in Fig. 1 (b). The example shows the elimination of a step *Prepare action* by enabling the interaction with IoT for the step *Act*. Hence, IoC in this context means that the execution of an activity is separated from its concrete implementation. However, this requires that process modeling languages are able to represent this kind of activities what is discussed later. A second aspect is related to the ability of IoT devices to communicate directly. Without IoT involvement there are activities that contain a manual retrieval of data from one device, their interpretation by a human process participants and a subsequent action based on the resulting information basis. If the interpretation part of this activity can be automated, the whole activity can be automated, too. The reason is that the communication between IoT devices can be standardized through protocols like MQTT.

Plain Control Flow vs. Data-driven Flow. Beside automation and control shifts, IoT provides the opportunity to enrich existing models with additional information that could not be obtained and, hence, could not be modelled with offline environments. Thus, so far control-flow dependencies between activities can now be justified by enriching them with data conditions stemming from IoT. We distinguish between three different types of data enriched conditions that have been defined in the context of multi-perspective declarative process modelling (Burattin et al., 2015): The *activation* condition is a statement that must be valid when a certain triggering activity happens. For example, whenever *Retrieve information* is executed and a certain sensor value v_1 is smaller than a certain threshold x, then eventually *Act* has to follow. The *correlation* condition is a statement that must be valid when the triggered activity happens and relates certain values of the triggering as well as the triggered activity. For instance, whenever *Retrieve information* is executed, then eventually *Act* must follow and the value for v_1 associated with *Retrieve information* must be the same as for *Act*. *Target* conditions exert limitations on values that are associated to the triggered activity. As an example, when activity *Retrieve information* is performed, then eventually *Act* must be executed and the value for a certain variable v_1 associated with *Act* must be x. Though the three condition types are well established, their applicability spectrum can be extended due to the availability of more sensor data and real-time data provisioning provided by IoT devices.

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Arbitrary vs. Efficient Resource Allocation. The enrichment of existing process models with additional information is not limited to data conditions. Due to the possibility of, for instance, location tracking of organizational resources it is possible to improve the overall process performance by a more efficient resource allocation. For example an activity that can be assigned to an arbitrary resource as long as this resource fills the compulsory role. IoT devices like GPS trackers are able to locate resources. Hence, it is possible to additionally define constraints on their distances to the location where the activity should be formed. The distance can potentially be replaced by any other property of human process participants that is tracked by IoT devices. The current section is intended to be a proof that process modeling can benefit from information and infrastructure provided by IoT. However, the examples are rather a baseline for further research and a first attempt for a classification of IoT influences on process modeling tasks. Hence, both the different influences and their classification should be investigated further in future research.

5 EVALUATION IN INDUSTRY

We describe the evaluation of the proposed concepts by means of an application in industry. The techniques have been implemented in a corrugation plant. The application of IoT devices and integration with the existing BPM system lead to several process improvements. IoT provides the opportunity for re-engineering existing process models. This is evaluated using the example of a real-life process for corrugated paper production. Among other aspects this process contains many *observation* tasks like, for instance, *Check stack height* or *Check remaining meters roll* followed by one or more *compensation* steps like *Tag stack* or *Prepare new roll*. Each compensation step is a successor of one observation activity. The latter gives humans insights about the state of the machines. Some states, for instance, *Max. stack height reached* and *Min. meters reached*, require human intervention and hence trigger a compensation step.

Before the emergence of IoT the observation tasks were performed as repetitions of manual information pull requests. It was up to the human process participants to gather and interpret these information periodically. Because of these repetitions the observation tasks have been intuitively foregrounded. Hence, the process model also focuses on these observation tasks rather than the impact of the *information* that are retrieved. The model shows a view of the tasks and their relationships that is limited to the functional and behavioral perspectives. Since the process mainly consists of activity pairs that are rather unordered and highly repetitive a declarative modeling style was used. With the emergence of IoT information can be provisioned without manual pull requests. Hence, the repetitive observation steps could be eliminated completely as it is shown in Fig. 2. This reduces the number of activities in the model and changes the emphasis to the actions that have to be taken to keep the process working. The model was enriched with information that are related to the data-oriented perspective. Without IoT these information were hidden in the knowledge of the human process participants.

Some tasks in the production process required the physical movement of human performers to a particular location. With IoT it is possible to perform interactions between these performers and the production machines ad hoc, i.e. without any physical movement. In the process model shown in Fig. 2 the steps *Adapt paper warp* and *Initiate machine cool down* are IoT-enabled activities. This means that the model now shows interactions between human participants and production machines explicitly and that latter are responsible for the performance of certain actions. IoT provided opportunities to rework a process model in terms of reducing the number of activities and changing types. Additionally the model could be enriched with information that are provided by IoT devices. Though these information can also be retrieved without involving IoT they have not been represented in the corrugated paper production process model. Since IoT makes these information explicit they became attractive for improving this process model.

6 CONCLUSION

We investigated how the enactment of a BPM application changes or must be customized through the transition of the real world through IoT technology. We described IoT characteristics and the interplay with BPM and outlined benefits and necessary adaptions w.r.t. the BPM lifecycle. Our discussion highlighted that the integration of IoT and BPM requires deep conceptual and technological adjustments in each phase of the BPM lifecycle. We tackled two concrete adaption tasks, i.e., we introduced generic concepts and solutions for IoT enhanced process modeling and a technological integration architecture. Finally, we implemented and evaluated our solutions in a corrugated paper production industry use case. For future work, we will focus on the different tasks that were skeched in the research agenda. We will adjust and apply a distributed declarative process mining ap-

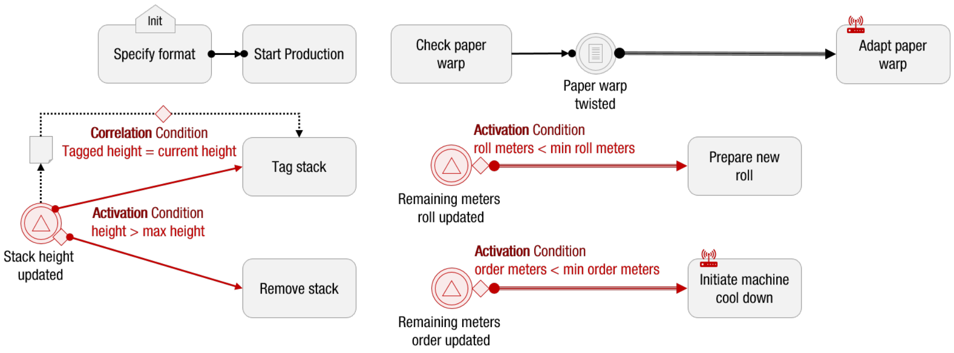

Figure 2: IoT enhanced process model.

proach (Sturm et al., 2017) to event logs in the described production industry scenario.

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