RESEARCH NOTES

Seven Paradoxes of Business Process Management in a Hyper-Connected World

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Abstract Business Process Management is a boundary-spanning discipline that aligns operational capabilities and technology to design and manage business processes. The *Digital Transformation* has enabled human actors, information systems, and smart products to interact with each other via multiple digital channels. The emergence of this hyper-connected world greatly leverages the prospects of business processes – but also boosts their complexity to a new level. We need to discuss how the BPM discipline can find new ways for identifying, analyzing, designing, implementing, executing, and monitoring business processes. In this research note, selected transformative trends are explored and their impact on current theories and IT artifacts in the BPM discipline is discussed to stimulate transformative thinking and prospective research in this field.

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1 Introduction

Business Process Management (BPM), as it is seen today, is a boundary-spanning research field that builds on and consolidates research on "[...] how to best manage the (re-)design of individual business processes and how to develop a foundational BPM capability in organizations catering for a variety of purposes and contexts" (vom Brocke and Rosemann 2010).

BPM can, therefore, be understood as an organization's core competency for managing all its business processes, from operational to managerial. BPM spans all functional areas in organizations, and networks an organization with its environment, including consumers and other organizations, such as suppliers and customers (and beyond that, with their suppliers' suppliers and their customers' customers). Based on conceptualizing organizations as socio-technical systems, BPM views business processes as organizational structures that are enabled by Information Technology (IT). Rosemann and de Bruin (2005) introduce a framework that illustrates the BPM field's diversity, comprising six capabilities: Governance, Strategy, Methods, Technology, People, and Culture. BPM is highly relevant for business success and has become a crucial organizational core competency for all kinds of organizations in their daily practice (Mullich 2011). Speaking even more generally, business processes are a primary component of an organization's DNA, since the performance of day-to-day work – such as business processes – even constitutes an organization as a social (or, more precisely, a socio-technical) structure (Giddens 1984; Beverungen 2014).

Breaking free from the three traditions of work simplification/quality control (engineering tradition), performance of the firm (management tradition), and digitalization (IT tradition) (Harmon 2006), the academic community of BPM researchers has contributed theories and IT artifacts that approach the management of business processes in its own right since the 1990s. For almost three decades, international conferences like (Association for Information Systems (AIS) 2017; BPM Community 2019; Institute of Innovative Process Management e.V. 2017), journals like (Emerald Group Publishing Limited 2017), or books like (Dumas et al. 2018; vom Brocke and Mendling 2018; vom Brocke and Rosemann 2014) have been reflecting the field's increasing significance, diversity, and maturity.

Increasingly, organizations face the phenomenon of *Digital Transformation*, an umbrella term pointing at a broad and fundamental economic (and related societal) change that is heavily influenced by disruptive IT. IT trends include, among others, ubiquitous internet access of myriads of physical devices, access to a vast amount of data, which can be reproduced and shared at almost zero costs (Brynjolfsson and McAffee 2014), algorithms that are able to process big data in real-time, as well as a global workforce that is capable of creating new business models from these new opportunities (Brynjolfsson and McAffee 2014). The *Digital Transformation* can be considered as a fundamental change that could prove to be equally disruptive as the industrialization of Europe in the 19th century (Brynjolfsson and McAffee 2014).

At closer inspection, the *Digital Transformation* of our society brings about a Hyper-Connected World (see also: World Economic Forum 2016), in which human actors and artificial actors are networked with each other via multiple communication channels. Hyper-connectedness allows to perform business processes in an entirely new way, but also increases the complexity of managing them in line with corporate or societal objectives. This trend appears to become so powerful and disruptive that it might fundamentally change the resources and capabilities that organizations and people require to manage business processes. In particular, organizations have to re-evaluate the rules of the game in order to build up the assets and core competencies required to remain successful in their industries. We take up this trend and investigate how some new technologies leave their mark on BPM in our society.

In this research note, we focus on four technological enablers for the fact that we consider their interaction with BPM as least understood: *Social Computing* as a paradigm for connecting individuals digitally, *Smart Devices* as digitized physical resources that join processes as artificial actors in their own right (e.g., Internet of Things, Cyber-Physical Systems), *Big Data Analytics* as a tool to automatically analyze extensive data volumes from business processes and their environments, and *Real-Time Computing* that enables organizations to analyze data in (near) real-time to adapt their business processes on-the-fly. Various other recent technologies are not discussed in detail, because their potential contribution to BPM is discussed elsewhere, including *Blockchain* (Mendling et al. 2018b), *Internet of Things* (Janiesch et al. 2017a), *Semantic Technologies* (Mendling et al. 2017a), *Artificial Intelligence* (Cangemi and Taylor 2018), and *Cognitive Computing* (Roeglinger et al. 2018). We identify how the selected technologies challenge the main tasks to be fulfilled by BPM stakeholders – including process owners (strategy), process analysts (modeling and analysis), and system developers (implementation) (cf. Fig. 1) – and
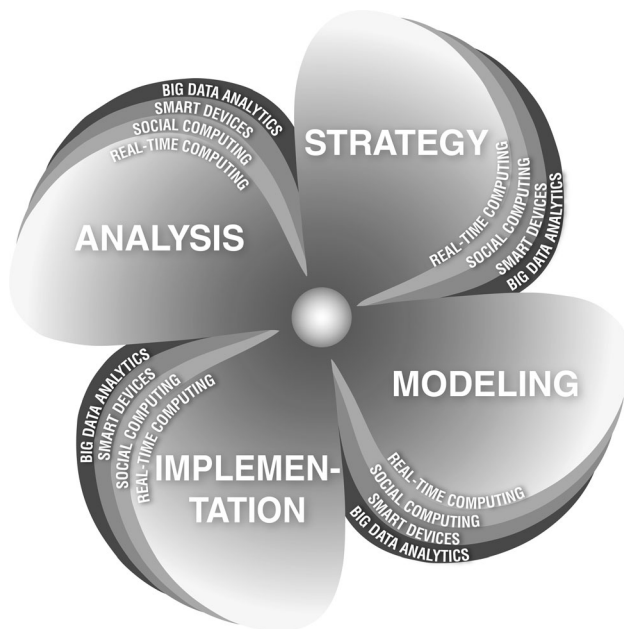
Fig. 1 BPM framework structuring this research note

discuss to what extent these challenges align or contradict each other, pointing to paradoxes that we need to resolve as a discipline. We defined these tasks in line with the BPM Life-Cycle Model proposed by Dumas et al. (2018) – a model that highlights core activities performed by business process managers, while it does not specify a process execution phase explicitly and puts less emphasis on how and why process participants execute/enact business processes in their day-to-day work.

This research note implements two objectives. First, we discuss recent developments in research and practice at the intersection of BPM and Digital Transformation. Second, we propose avenues for future research to advance our understanding of BPM in a hyper-connected world. We expect these trends to profoundly transform theories and IT artifacts that currently constitute the BPM discipline, such that theories have to be tested and refined, whereas IT artifacts need to be (re-)designed and (re-)evaluated. Beyond that, we anticipate entirely new challenges to emerge that require novel theories, as well as new classes of IT artifacts, which – in the past – were impossible to develop without the hardware capacity available now. While we do not claim to cover all aspects of BPM, we intentionally focus on operational processes, which were identified (Westerman et al. 2011) as one of three crucial areas affected by the *Digital Transformation*.

The paper is structured as follows: in Sect. 2 the four selected IT enablers are introduced in more detail. Subsequently, the enablers' implications on the BPM discipline are being reflected (Sect. 3), followed by discussing

avenues for future research in BPM (Sect. 4) and a concluding call for action (Sect. 5).

2 Four Information Technology Enablers

In our joint research project RISE_BPM, we explored four information technology enablers, comprising *Social Computing, Smart Devices, Big Data Analytics, and Real-Time Computing*. Subsequently, we briefly present each enabler and some of its impacts on the BPM field.

2.1 Social Computing

For white-collar workers and customers alike, *Social Media* present an opportunity to network with each other and establish digital communities that foster communication, cooperation, and collaboration on a group level.

Social Media are means to make information, such as personal opinions, facts, recent experiences, and stories available at different levels of public accessibility. They enable users to communicate with a theoretically unbounded crowd of other people about products and the companies providing them. Based on these interactions, *Social Media* contain a partially unfiltered source of information that typically transcends the boundaries of a single organization, club, association, or company. *Social Media* can be as diverse as online forums, including blogs, company-sponsored discussion boards and chat rooms, consumer-to-consumer e-mail, consumer product or service ratings websites and forums, Internet discussion boards, and social networking websites, to name a few (Kaplan and Haenlein 2010).

User-Generated Content (UGC) has a significant impact on tools and strategies adopted by companies to communicate with their customers (Mangold and Faulds 2009). In *Social Media*, data are published with a direct attribution of the author and the exact time and date of publication. The main content of the message is conveyed through natural language, thus making published data semi-structured. Limiting their automated interpretation, user-generated content often contains abbreviations, idiomatic expressions, and emoticons. Tags and links enrich the semantics of a message, which is critical to conduct machine-driven information linkage.

Still, the extraction and analysis of this UGC can represent a valuable source of knowledge to companies. Examples of such sources of information include complaints via Instagram posts about the delivery of a defected product, or suggestions for improvements via the product user forum of an e-mail service provider, as well as tweets about a recent patent, publication, or released product from the creator. For instance, DELL has analyzed social media

posts to identify more than 550 new ideas for their products based on analyzing UGC on their online community *Idea Storm* (Gardner 2014). The opportunities related to analyzing UGC have lead to a florescence of data mining techniques applied on customer information to ameliorate customer relationship management (Ngai et al. 2009).

Within their own boundaries, many organizations offer their workforce collaboration tools – including *Groupware* applications and *Corporate Social Media* – to enable them to perform knowledge-intensive processes and knowledge work. White-collar workers take advantage of the tools to communicate, cooperate, and coordinate their activities. Tools include, among others, instant messaging, e-mail (Geyer et al. 2006), and tools for designing and executing ad-hoc workflows. Taken together, *Social Media* represent a good deal of the communication and information sharing means used by employees to manage their day-to-day work and provide a valuable means to connect process actors, stakeholders, and clients on a shared public platform. The business processes conducted with these tools often represent rather informal, non-routine processes that do not fit well with the top-down design of mass transaction processes that are often implemented in a Business Process Management System (BPMS).

As communication tools, *Social Media* can also be used to perform follow-up work on standard processes that are conducted in enterprise systems. For instance, employees might be quickly asking for support during a process via, e.g., their private Skype accounts. Having so much important activity occur outside and beyond the awareness of an enterprise application degrades the application's effectiveness and management value. For this reason, companies nowadays tend to offer their employees tailored *Social Media Platforms* to exchange process-focused information (Bernstein 2000) within their organization. Preserving the "soft knowledge" of the overall process is of critical importance, in particular in the area of knowledge-intensive processes (Di Ciccio et al. 2015) and artful processes (Di Ciccio and Mecella 2013; Hill et al. 2006), that is, processes whose conduct and execution are heavily dependent on white-collar workers performing various interconnected knowledge-intensive decision making tasks.

On a meta level, *Social Media* are repositories of recent relevant facts that the authors want to make available to their colleagues, friends, or acquaintances. Those facts could enrich, specify, or glue together events that are recorded by BPMSs or other intra-organizational IT systems by embedding a process into contextual information, e.g., to explain things that could otherwise be less explicable, very often articulated in the words of the people involved directly.

2.2 Smart Devices

The introduction and proliferation of *Smart Devices* is an earth-shattering event that will profoundly change information processing and business models in our world. In 2017, Gartner Inc. (2017a) stated "[...] that 8.4 billion connected things will be used worldwide in 2017 [...], rising up to 20.4 billion by 2020. Total spending on endpoints and services [related to the Internet of Things, IoT] will reach almost \$2 trillion in 2017." That said, in the Gartner HypeCycle, the IoT is still viewed as being at the (first) peak and/or sliding into the trough of disillusionment (Gartner Inc. 2017b).

Smart Devices are equipped with sensors that can detect their own status as well as physical and digital events in their proximity. They have build-in hardware to store and process data to reason autonomously about the data they collect. They feature actuators that can perform physical actions inside a device and/or in a device's proximity, while they have connectivity to transmit and receive digital data to/from their environment (Beverungen et al. 2019), i.e., from other devices and information systems, including Workflow Management Systems (WfMS) and Enterprise Systems.

Smart Devices are expected to profoundly transform various industries, including transport and logistics, healthcare, and manufacturing as well as the individual domains of living and social interactions (Atzori et al. 2010). As artificial actors in their own right, myriads of *Smart Devices* – including smart meters, smart vehicles, smart machines, smart phones, and others – will be starting, conducting, influencing, and ending business processes. Their build-in features will make *Smart Devices* partially autonomous, such that their actions cannot be controlled by one central authority, such as a business process engine. This shift of control means that business processes will be conducted a lot more decentralized, which will render top-down process engineering unfeasible, shifting control from build-time to run-time.

Moreover, the emergence of *Smart Devices* adds a physical perspective to business processes; while faulty processes in digital execution environments might be rolled-back, it might be impossible to undo physical actions that have been performed. Therefore, business processes that lead to physical actions performed by *Smart Devices* must be fail-safe to prevent adverse consequences of business processes.

First industrial business processes have been transforming to incorporate the benefits of *Smart Devices*, many of them stemming from the machine tools industries, in which production technology has been equipped with automation technology for a long time. Continuing this tradition, connecting a machines' internal data processing

capabilities with the "world outside" seemed like the next logical step, such that many current cases and prospects (Atzori et al. 2010; Perera et al. 2010) focus on sensing events in the field and taking these events up in business processes. For instance, Oracle reports a case in which a smart equipment senses outages proactively – based on acquiring data on themselves and on their environment – and reports the outages as events to remote information systems (Acharya 2015). These information systems listen for events and start the execution of pre-defined business processes (for instance, maintenance processes aimed at fixing the equipment) as soon as these events have been thrown.

Another case that utilizes *Smart Devices* to perform physical actions is situated in Hamburg, where "300 roadway sensors were installed by the Port Authority in order to monitor, control and manage roadways traffic" (Ferretti and Schiavone 2016, p. 278). For instance, since movable bridges are being opened on arrival of a ship, the road traffic in the port can be diverted to alternative routes now. In addition, the "system also calculates the weight of vehicles in order to establish the volume of traffic on the 140 bridges available in the port for trucks and trains and provide useful information for the design, maintenance and restructuring of these infrastructures" (Ferretti and Schiavone 2016, p. 279), to improve the port's "integration with customers, reduce direct contacts and formal information exchanges with them and, finally, made easier and shorter their decision-making process" (Ferretti and Schiavone 2016, p. 279).

2.3 Big Data Analytics

Increasing amounts of data have been recorded for decades now (Hilbert and Lopez 2011), many of them generated by the trends for *Social Computing* and *Smart Devices*. This development is often referred to as *Big Data*, which in general means that each of the "four V's" is at play: Volume, Velocity (data grow quickly), Variety (data are heterogeneous), and Veracity (data quality varies). Big data as such does not always refer to large datasets, but could also indicate small but complex datasets.

In general, data are increasingly collected for general purposes and do not refer to a single goal or type of analysis. The main challenge is to make sense of the available data, using the right data and analysis techniques. In recent years, the field of *Data Science* emerged, which is an amalgamation of different sub-disciplines (van der Aalst and Damiani 2015): statistics, data mining, machine learning, process mining, stochastics, databases, algorithms, large scale distributed computing, visualization and visual analytics, behavioral and social sciences, industrial engineering, privacy and security, and ethics. Of these

areas, *process mining* bridges the gap between big data and data science to BPM.

Process mining answers crucial BPM questions, based on analyzing data from event logs. An event log contains a collection of events, where each event corresponds to: a *case* or process instance (e.g., an order number), an *activity* (e.g., evaluate request), a *timestamp* to indicate when the activity was executed, and additional (optional) *attributes*, such as the resource executing the corresponding event, or the type of event (van der Aalst and Damiani 2015).

Based on the data provided in the event log, process mining covers three main aspects: *discovery* of a process model (e.g., BPMN model or Petri net) based on event data; *conformance checking* of event data with respect to a provided (or discovered) process model; and *enhancement* of a process model by using event data to project, for instance, time information on the process model in order to analyze the performance of the business process.

Extending the conventional approach to mine processes based on event logs, the analysis of *Big Data* allows putting data on business processes into a context of other events that are related to a process. These additional data might, e.g., be provided on *Social Media* or by *Smart Devices*, as sources of data that might extend, complement, or even contradict data stored in BPMSs. A crucial prerequisite for making these data usable is to assure data quality and an adequate degree of granularity (e.g., consistent process IDs), such that the data can be mapped to process data supplied in event logs.

Within our project, we investigated how contextual information about process instances and activities is causally related to process performance over time. For example, the resource executing a particular activity in the process can influence the overall case duration and/or quality, since more or less rework is required. Another question is how different schedules for different resources can have an influence on the waiting time for activities performed by those resources. This, in turn, can affect the total duration of a process.

Another example is the analysis of health care event data in order to identify how patients are treated in a health care organization. Questions like "what is the most common treatment process', "among which persons are handovers performed in an organization", or "how efficient are processes in a hospital" can be answered using healthcare event data, as has been done for a Dutch hospital (Mans et al. 2009). However, the issue is that disease treatment is not structured, despite clinical guidelines and pathways, due to the combinations of diseases, patient characteristics and variability in medical staff. Providing insights into these processes, using the recorded event data, can result in re-designing and improving the business processes.

2.4 Real-Time Computing

Recent advances in data processing, allowing for higher data volumes due to distribution, have enabled the development of technologies that are capable of processing a huge amount of information in real-time. This means that organizations can leverage this information instantly and take immediate action to adapt operational processes and corporate strategies to the ever-accelerating pace of business. Note that when we talk about real-time, we do not refer to the classical meaning of real-time systems in which tasks have hard deadlines and timing faults may cause catastrophic consequences (e.g. car automated safety systems) (Stankovic 1988). Instead, in this context *Real-Time Computing* refers to the so-called near real-time, in which the goal is to minimize latency between the event and its processing so that the user gets up-to-date information and can access the information whenever required.

Amongst the technologies that have fostered the use of *Real-Time Computing*, we highlight four of them with a strong impact in a business context. *Complex event processing* (CEP) enables filtering, composition, aggregation and pattern-detection of events that come from multiple sources, such as customer orders or social media posts (Cugola and Margara 2012). *In-memory analytics* involves the use of Random Access Memory (RAM) to store and analyze data, in contrast to traditional analytics in which data are stored on disks. This results in significant performance gains that allow business users to experiment with customer data in real-time and hence, to make timely decisions (Acker et al. 2011). *Big data stream analytics* enable the real-time processing of streams of data that have high volume and velocity by relying on parallelization platforms like Apache Spark Streaming (Zaharia et al. 2013). Finally, *data stream mining* performs traditional data mining techniques with continuous rapid data records. This includes techniques that can produce acceptable approximate mining results to cope with the high data rate of data streams as well as capturing the changes of data mining results coming from the evolving nature of data streams (Maimon and Rokach 2005).

These *Real-Time Computing* technologies provide BPM with the necessary tools to leverage intelligence instantly and make evidence-based timely decisions. This means that the traditional division of on-line transaction processing (OLTP) and on-line analytical processing (OLAP) can be overcome, making real-time process execution viable. Doing so is critical in a digitized and globalized environment in which organizations must adjust their processes at maximum speed and, at the same time, they have to make sure that their decisions are based on proper data and analytics. Connecting with *Social Media* and *Smart Devices*, this implies that business processes can be started, conducted, influenced, and stopped from outside classic BPMSs.

There are many different situations in which real-time computing brings clear advantages to BPM. For instance, real-time business activity monitoring can support decision-making to react faster to different situations. For example, a movie streaming service company tracks instantly which films are most popular among its customer segments so that their content team knows which films they should promote (Oxford Economics 2011), or an airline company that uses real-time information to manage seat availability for its 2000 daily flights with the goal to put as many travellers on board as possible (Oxford Economics 2011). Another case in which *Real-Time Computing* brings significant advantages is the immediate detection of non-compliance situations or fraud. For instance, a payment platform leverages big data stream analytics to detect fraudulent credit card payments (Li 2017).

3 Implications for BPM

Given the four enablers presented in the previous section, and considering four typical phases of BPM (cf. Fig. 1), the authors conducted a workshop session,[1] supplemented by follow-up discussions. In the workshop session, groups of 3–4 researchers discussed how – from their point of view – one of the identified technological enablers impacts the BPM discipline. All researchers involved in this session had a long standing record of projects and publications in the BPM field. As a result, a total of 60 consequences for the BPM field were identified. These consequences were presented, discussed, and consolidated in the entire group of 16 researchers. From the consolidation step, 23 ideas emerged, pointing to eleven challenges. Thus, while the statements developed by individual researchers might initially have reflected their subjective points-of-view on the BPM discipline, we followed a consensus-oriented interpretivist research approach that was promoted by the diversity of our viewpoints on the BPM discipline. This approach is an established epistemic theory of truth for conducting research on conceptual modeling (Becker and Niehaves 2007). Subsequently, we present these challenges in terms of the four main categories we selected.

3.1 Strategy

The emergence of the IT enablers requires closer integration of the four phases contained in our framework, and speeds up a process's life-cycle itself. Also, business

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processes might have consequences in the physical world, which greatly impacts their governance and management.

Challenge 1 The main strategic challenge for organizations is the need to adapt their processes at an ever increasing speed, to follow up on the technological advancements that influence BPM. This means that organizations need to speed up a process's life-cycle, changing the process more often, maybe even continuously. One way to achieve this is to *integrate the activities in a process's life-cycle more tightly*, for instance by linking the modeling, implementation, and analysis phases through the data created and used in process execution. First concepts on integrating AB-Testing and BPM have been proposed in this direction (Satyal et al. 2019). The trend for continuous adaptation will likely divert management attention and resources away from transformational re-engineering initiatives to incremental on-the-fly improvements of business processes, at least if the underlying IT infrastructure of a business process remains largely unchanged – termed the third wave of BPM (Smith and Fingar 2003). In regard to the BPM workforce, we expect that the traditional gaps between process analysts, process owners, process designers, and process participants will disappear, in favor of establishing *interdisciplinary teams*; a similar trend can be observed in applications management, where *(Biz)DevOps* establish teams that include software developers, operators, and users (Bass et al. 2015).

Challenge 2 A hyper-connected world leverages the emergence of *omni-channel* interactions between companies and customers (Verhoef et al. 2015). With the rise of *Social Computing*, companies adjust their strategies to use appropriate communication channels to interact with their clients (Tiago and Veríssimo 2014). Implementing omni-channel strategies means that business processes *will span across more tools* than today (Mangold and Faulds 2009). This fragmentation necessitates linking data from diverse systems and establishing identifiable process IDs – both are crucial prerequisites for making process mining and other data science approaches work. On the clients' side, the openness of *Social Media* enables customers to network with other customers they might not know personally. While social media enables networks of customers to become participants in a business process, the communication on *Social Media* is (at least partially) public. While benefits of using social media for BPM include integrating BPM stakeholders into the design, modeling, implementation, execution, and process improvement (Erol et al. 2010), they add complexity to managing and performing business processes, too.

Challenge 3 Caused by the emergence of *Smart Devices*, business process execution can have *physical consequences*

that – other than purely digital processes – cannot be rolled back. For instance, business processes could set physical devices – such as bridges or vehicles – in motion. As long as business processes were confined to the digital world of software systems (e.g., BPMSs, Process Engines, and Enterprise Systems), errors in business process instances could be resolved by database roll-backs or other corrective digital operations. In a world in which business processes have physical consequences issued by *Smart Devices*, such corrective actions might no longer be viable. In this world, business processes might become safety-critical and demand much higher degrees of reliability and process quality that are beyond the capabilities of current IT artifacts used in BPM (Meroni et al. 2017). Moreover, this issue *contradicts the decisions and actions* that process designers might conduct based on probabilistic methods in *Big Data Analytics*, since these methods are subject to uncertainty when predicting unobserved data (Ghahramani 2015). Thus, the applicability of probabilistic data science approaches might remain limited to digital-only business processes and to processes for which enough data are available to train the model adequately. If unresolved, this restriction to digital processes is a profound one, since it would severely limit the ability of process participants and process managers to apply data science to processes that influence the behavior of smart devices.

Challenge 4 The introduction of *Smart Devices* into business processes as actors in their own right increases the complexity and unpredictability of business processes, since decisions will no longer be made by one central business process engine alone. Soon, chat bots might play a bigger role in processes such that their interactions with a BPMS need to be specified (Mendling et al. 2018a). As a consequence, data associated with one business process will be scattered across various software systems and *Smart Devices*. Scattered process data and distributed process control will create entirely new challenges in regard to the complexity and accountability faced by process participants conducting a business process. In addition, process managers will need more effective and efficient methods to re-integrate data on a business process, before meaningful analyses of process data can be performed.

3.2 Modeling

In a hyper-connected world, process modeling must feature additional modeling constructs, while conceptual models must be integrated more closely with field data and the workflows implemented.

Challenge 5 Business process modeling languages must support additional constructs to include new data and effects related to the four IT enablers. For instance, process

modeling languages must have the right level of abstraction to deal with the diverse data involved, from a top-down refinement of business processes to a bottom-up (re-)organization through data retrieved from event logs and sensors (Janiesch et al. 2017b). A holistic approach would allow stakeholders to seamlessly navigate through different levels of abstraction, to use process models as efficient means to communicate about a process from different angles. Future modeling languages also need to integrate activities/control flows more tightly with analytics/decision making, as a foundation for real-time process execution. From a human-centered perspective, the beliefs, intentions, desires, feelings, decisions, collaboration, and contingency events of human agents designing or performing processes could be modeled to account for the unpredictable nature of knowledge-intensive processes (dos Santos França et al. 2015). Finally, current process modeling languages do neither address *Social Computing*, nor *Smart Devices* (both of them can be sensors or actuators in a process) with their native constructs.

Challenge 6   Process models need to be more tightly integrated with both the implemented workflow models and with the process data generated while performing processes. In addition, process models need to be designed more efficiently to save resources and to put them into operation more quickly. This can be an advantage for addressing Challenge 1 too, since it would speed up a process's life-cycle based on using process models to bridge field data with implemented workflows. One way to speed up the modeling process is to build on best-practice knowledge obtained from process handbooks, reference model collections, or from process participants' expertise (Mendling et al. 2017b). Automatic text analyses might prove useful to identify reference processes from collections of unstructured texts (Friedrich et al. 2011). Process mining might serve to detect variations and workarounds (Alter 2014) in business processes. Also, advancing modeling languages includes the provision of a tighter integration of modeling choices in the process with decisions made during run-time, based on the available process data and other input.

3.3 Implementation

From the perspective of process engines, the advent of *Social Computing* and *Smart Devices* highlights the need to roll out processes across distributed systems that might include various information systems and physical objects. Also, workflows must be implemented into organizations and software systems more quickly, be consistent with conceptual models, and be based on hard field evidence

and data analytic capabilities, to direct their control flow on-the-fly.

Challenge 7   While many of the challenges discussed before increase processes' complexity, we see a strong challenge to simplify the implementation of all the extra features (La Rosa et al. 2011). For instance, the different data sources, devices, and social media channels that affect a business process must be efficiently connected to process information systems. This includes the ability to leverage available data at near real-time while executing a process, i.e., to enable process analysts to analyze activities at run-time, and to offer process participants evidence-based recommendations concerning a process's control flow.

Challenge 8   In line with the distributed socio-technical environment in which processes will take effect, business processes must be implemented and deployed across diverse applications, *Smart Devices*, and social systems. For instance, *Smart Devices* will act autonomously depending on their own sensor data, which limits a process engine's ability to control a business process fully. This lack of control requires to introduce new strategies to govern and direct the execution of process instances in distributed settings, making sure that the process's execution complies with predefined standards. At the same time, implementing a business process also becomes more complex if the process includes more (and more diverse) process participants and organizations. This increasing complexity motivates reflecting and updating strategies (Kettinger et al. 1997) and best practices (Mansar and Reijers 2005) for re-designing business processes. Beyond adjusting process re-design, research evidences that process participants often work around or deviate from predefined business processes (Alter 2014). In a distributed environment, workarounds and variability might effect other participants, information systems, and devices (Wolf and Beverungen 2019). In a hyper-connected world, business processes will, therefore, exhibit more variability, become more unpredictable, and are more difficult to control with current methods.

3.4 Analysis

Process analysis must built on much broader and deeper data, comprising event logs and myriads of other data points generated by diverse information systems, users, and *Smart Devices*. Based on these data, analytics can, therefore, have a much greater impact on processes in the future, but we must solve the obstacles associated with making these data usable, which range from data quality issues to matters of data privacy, data security, and responsible data science.

Challenge 9   The main analysis challenge is the correct and simple application of data analysis techniques and a correct interpretation of their results. For instance, predictive analytics currently is actively researched, but it is not yet practically applicable (Teinemaa et al. 2019). Due to the amount of data that is available for analysis, the discipline still struggles to translate data analysis into process improvements that have strategic importance, closing a process's life-cycle. Analysis techniques should be expanded beyond a 'single focus' perspective, and be able to automatically include domain knowledge that enable analysts to interpret the results in their context (de Medeiros et al. 2007). Furthermore, more efficient or even simpler visualization of the results is needed to ease the access of the analysis outcome not only for specialized consultants but also for process participants (Buijs et al. 2014; Lieben et al. 2018).

Challenge 10   With the use of *Social Media* and *Smart Devices*, the additional data generated need to be included in the analysis phase to add context to a business process. This can go so far as to identify a complete state of an organization, by integrally analyzing all activities and resources. Since many of the data required for this purpose will be unstructured and were never meant to be used for analyzing business process, the data must be processed to make them available on a sufficient level of quality. The analysis techniques must involve the adoption of Natural Language Processing (NLP) techniques to allow for the correct labelling and interpretation of human-written information outside the scope of the automated IT systems logging (Leopold et al. 2014). Also, analysis techniques must be able to interpret, enrich, integrate, and filter data from multiple sources, where data are stored not only in a structured manner, as they can be semi-structured or unstructured (Di Ciccio and Mecella 2013). Content-wise, we need new techniques that can cope with specific data characteristics, such as beliefs, desires, and intentions of process participants, but also machine states and physical actions, as well as unstructured data that might be noisy, leading to more extensive data preparation activities before meaningful analyses can be performed. Many of these challenges are due to the properties of knowledge-intensive processes that are particularly subject to decisions made by participants performing a business process (Di Ciccio et al. 2015).

Challenge 11   Like data science in general, business process analysis techniques need to follow the principles of responsible data science, including fairness, accuracy, confidentiality, and transparency (van der Aalst et al. 2017). The importance of those principles becomes prominent even more because of the rapidly increasing amount and reach of data stored in a process context,

including *Social Media* and *Smart Devices*. In particular, identifying beliefs, desires, and intentions of human process participants in processes brings about ethical concerns regarding false interpretations made from analyzing the data, in particular so if these insights are made public. Ethical guidelines for data science do not only apply to personal data used in a process, but they also need to be respected when analyzing process participants' performances in a process. For instance, methods for identifying social networks with process mining (van der Aalst et al. 2005) must be designed and used to comply with ethical guidelines (Fahrenkrog-Petersen et al. 2019).

4 Discussion

While the challenges identified in the preceding section seem valid in their own right, a closer look revealed that some of them influence – or even contradict – each other. On a higher level of abstraction, then, we consolidated the challenges to identify seven paradoxes that the BPM discipline must solve when developing new theories and IT artifacts. The paradoxes highlight the need to perform integrated research cycles, which consider the dialectic properties of these aspects.

Paradox 1: Propelled by the introduction of *Social Computing* and *Smart Devices*, strategies, models, implementations, and analyses of business processes become more complex, whereas a process's life-cycle speeds up and requires tighter integration. We need to develop new technologies and organizational ideas to achieve both of these conflicting objectives at the same time. An important aspect can be to re-define traditional roles of process managers and process participants.

Paradox 2: Modeling languages must feature additional modeling constructs to grasp additional information on a process, which will increase process models' complexity. Still, conceptual models must be designed more efficiently and at lower cost. We need to design modeling languages that satisfy both requirements at the same time, based on reducing complexity – where possible – and guiding modelers through the design process in an efficient way. Also, the models must be made actionable as artifacts that seamlessly link the conceptualization, implementation, and data analysis of a process.

Paradox 3: Process execution and data analysis must converge to enable process participants to make real-time decisions when performing a process. However, process execution environments and process data become scattered across different organizations, information systems, and *Smart Devices*, leading to noisy, incomplete, or contradictory data. These deficiencies call for performing more complex data preparation activities that stand against real-

time decision making. Process managers have to decide what process performance dimension(s) to prioritize and to what extent performing data preparation activities is necessary and justified from a business perspective.

Paradox 4: Big data on processes must be analyzed in near real-time to fine-tune process execution. Many data analysis approaches used for this purpose are probabilistic, and the recommendations made with these methods are not always traceable to the data. On the other hand, in a world that is permeated by *Smart Devices*, processes might have physical manifestations that display safety-critical properties, which conflict with using (potentially inaccurate) probabilistic algorithms. Both aspects need to be reconciled, to enable process participants to adapt business processes where needed, while complying with safety requirements.

Paradox 5: Due to their increased complexity, IT artifacts for BPM are more difficult to conceptualize and implement, which leads to increased resource consumption. Furthermore, processes are subject to autonomous actions performed by people and by *Smart Devices*, which might render efforts to steer a process with a central business process engine useless. Therefore, we need to clearly identify in what scenarios it will pay off to apply the resources needed to define standardized processes – and what scenarios will have an intentionally incomplete definition, recognizing the ability of humans and artificial actors to adapt a process where needed.

Paradox 6: Companies are faced with a need to standardize most of their business processes, to capitalize on economies of scale and reduce process costs. In addition, the autonomy built into *Smart Devices* will make products adaptive to their use and context, leading to individualized products. Individualization of products will then bring about individualized service processes, which contradicts efforts for their standardization. Companies are, therefore, challenged to manage some parts of a process for efficiency, while other parts of a process must be managed for business value. The BPM discipline must develop theories and artifacts that allow managers to reconcile both objectives, based on applying methods on a higher level of abstraction.

Paradox 7: IT artifacts for BPM become more complex, while their evaluation requires hard field evidence that is based on data. Since performances and data of a process might differ across scenarios, the same process will likely evolve quite differently in each context. This dependency on field evidence interferes with the mission of design science research to develop theories for design and action (Gregor and Jones 2007) that hold true beyond individual contexts (Gregor and Hevner 2013), thus making design science projects more difficult to plan and to document.

5 Conclusion

In this research note, we identified some information technology enablers that promote a hyper-connected world, and inferred some implications for strategizing, modeling, implementing, and analyzing business processes. As we have discussed, these trends display disruptive potential that question many of the taken-for-granted theories and IT artifacts in the BPM discipline. In particular, the challenges we presented strongly point at an increasing level of complexity associated with BPM, while processes also must be implemented more quickly and more frequently. To foster a discussion and point at the next steps for research in our discipline, we operationalized these conflicting developments with seven paradoxes that will leave a strong mark on future research on business processes.

An overarching issue in the challenges and paradoxes we identified is the need to integrate the design – performed by process owners, process analysts, and system developers – and the execution of business processes – performed by process participants – further. Future BPM research needs to identify to what extent shifting and recombining traditional roles in BPM can work as a strategy to solve the paradox of managing processes at increasing speed and complexity. One idea towards that end is building on theory on organizational routines (Pentland and Feldman 2008) to investigate how performances of business processes may contradict and refine IT artifacts as well as organizational structure.

We would like to invite other researchers to help propelling the BPM discipline into this new age. As a guideline for performing this research, we state that it is important to be mindful of the paradoxes identified in this article, to establish a consistent body of knowledge on BPM that does not suffer from local optima.

Finally, cooperating in our project proved that we can draw great potential from an inter-disciplinary and international cooperation of researchers that integrates – and at times reconciles – a business perspective and a more technical perspective on business processes. We strongly encourage other researchers to do the same; after all, BPM rightfully claims its place as a boundary-spanning discipline.

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