Business Process Management in the Digital Age: Advancements in Data, Networks, and Opportunities

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Abstract

Business Process Management (BPM) is the art and science of managing distributed work, involving various activities, resources, and actors. The increasing prevalence of digital technologies, known as digitalization, affects individuals, organizations, and society as a whole. Business processes themselves, as well as BPM as a management discipline, are also heavily affected by digitalization, specifically in six overarching topics, namely data, networks, opportunities, humans, context, and change. In order to shed light on the ways in which digitalization affects the BPM domain, this doctoral thesis contributes to the latter three overarching topics: data, networks, and opportunities.

The overarching topic of data refers to attempts to capitalize on the increasing availability of data, leading to evidence-driven analytical methods and data-intensive business processes. In the context of digitalization, significant advancements in the field of machine learning led to promising new approaches for analysing structured and unstructured data. However, these advancements remain largely unexploited in the BPM domain. Therefore, research paper #1 focuses on the potential impact of deep learning on process outcome prediction. The paper reports on a structured comparison of a deep learning classifier and a classical machine learning classifier, based on five different event logs. The results show substantial potential for deep learning in process outcome prediction. Research papers #2 and #3 focus on the analysis of unstructured data, exploring the potential for cognitive computing in BPM. In doing so, research paper #2 develops a framework for structuring Cognitive BPM use cases. Based on these results, research paper #3 proposes a Cognitive BPM reference architecture.

The overarching topic of networks refers to a view of processes as parts of interconnected networks instead of single units of analysis. Research papers #4 and #5 highlight the need to take the interconnectedness of processes into account when prioritizing processes for improvement. Building on literature related to process improvement, process performance measurement, and network analysis, the research papers propose an approach for ranking processes according to their network-adjusted need for improvement, taking process interconnectedness into account.

The overarching topic of opportunities highlights the need for an opportunity-centric mindset in the context of BPM. This is necessary in order to identify the potential of emerging digital technologies, new regulations, and demographic shifts for the BPM domain. Fostering the fusion of the digital and the physical worlds, the Internet of Things (IoT) is regarded as one of the most disruptive emerging digital technologies, yet offers great potential to the BPM domain,

e.g., for higher automation, more accurate data collection, reduced errors, and overall efficiency gains. To enable the tapping of this potential, research paper #6 develops design principles which foster the success of IoT ecosystems. Research paper #7 takes an economic view, shedding light on the assessment of the customer value of IoT-solutions from an industrial company's perspective.

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I Introduction

Today, value creation is characterized by an extensive division of work, and is largely performed in complex value chains involving various actors within and across companies. In order to deliver products and services that meet and exceed customer expectations, coordination of the involved actors is of paramount importance (Mendling et al. 2017; Dumas et al. 2018; Frese 2000). Efficient and effective coordination within companies also creates and sustains competitive advantage (Bititci et al. 2011; Kohlbacher and Reijers 2013). Business process management (BPM) can be seen as the conceptualization of coordinating work in order to ensure consistent outcomes, and to systematically adapt and respond to emergent threats and opportunities (Bititci et al. 2011; Dumas et al. 2018; Harmon 2007). BPM supports companies in their efforts to achieve operational excellence and capitalize on opportunities to improve. Consequently, BPM is a subject of continuing interest among researchers and practitioners (Frese 2000; Mertens 1996; Rosemann and vom Brocke 2015; van der Aalst 2013; vom Brocke et al. 2011).

As a discipline, BPM is rooted in late 19th century studies of organizational design, which were carried out as the second industrial revolution set focus on mass production, the division of labor, and the use of electrical energy (vom Brocke and Rosemann 2015). However, the theoretical results generated by such research did not lead to significant benefits in practice until the advantages brought by the work of Porter (1985), Deming and Shewhart (1986), Davenport (1993), Hammer and Champy (1993), and Scheer (1994) (Houy et al. 2010). Back then, research on BPM followed two research streams: statistical process control and business process reengineering (Hammer 2010). Statistical process control focused on the continuous improvement of processes via the collection of performance data and the use of statistical techniques to identify the ‘root causes’ of performance problems (Deming and Shewhart 1986). Improvement initiatives usually involved small changes being made to existing processes. By contrast, business process reengineering emphasized the need to view processes as end-to-end work across the enterprise which creates customer value, and process improvement initiatives usually resulted in major changes to existing processes or even the design and implementation of completely new processes (Hammer and Champy 1993). Over the years, BPM significantly evolved and matured into the more comprehensive discipline of industrial engineering (vom Brocke and Rosemann 2015). The widespread agreement was that BPM represented a critical asset required to sustain the performance and competitiveness of companies. Coupled with the increasing importance of information technology (IT), this transformed BPM into an inclusive management discipline (Harmon 2007; Rosemann and vom Brocke 2015). Today, BPM encompasses the identification, design, execution, analysis, and improvement of business processes, and includes an established set of principles, methods, and tools combining knowledge from management sciences, IT, and industrial engineering. The overarching goal of BPM is to improve process effectiveness and efficiency in order to maximize business success (Poeppelbuss et al. 2015; van der Aalst and van Hee 2004; van der Aalst 2013; Weske 2012). In contrast to, e.g., industrial engineering, all types of processes are encompassed by BPM, including business, support, and management processes.

Among the most common approaches to structuring BPM are lifecycle models and capability frameworks (Poeppelbuss et al. 2015; van der Aalst 2013). Lifecycle models structure BPM in terms of the (management) activities which occur during the ideal-typical lifecycle of a business process (Houy et al. 2010; van der Aalst 2013; Weske 2012). Although there are many conceptualizations of the BPM lifecycle and activities involved, the different conceptualizations vary only slightly (Macedo de Morais et al. 2014). Most BPM lifecycles involve the following activities: process design and modeling, process implementation and execution, and process optimization and improvement (Houy et al. 2010; Macedo de Morais et al. 2014). Research which approaches BPM from a capability perspective has yielded various BPM capability frameworks. Capability frameworks enable a comprehensive conceptualization of the application domain, and generally consist of core elements, capability areas, and single capabilities. Single capabilities represent an organization's non-transferable resources and processes, and can be grouped into capability areas (Dreiling and Recker 2013). Core elements capture fundamental features of the application domain and help to group similar capabilities areas (Forstner et al. 2014). De Bruin and Rosemann (2007) proposed a BPM capability framework which provides an inclusive view of the BPM domain (i.e., it covers all the core elements of BPM). They developed the framework using a rigorous methodological approach (i.e., a Delphi-study), and the result has been widely adopted in industry and academia (i.e., more than 1,000 citations in scientific literature) (Looy et al. 2017). The framework consists of six core elements, which allow a comprehensive conceptualization of BPM (De Bruin and Rosemann 2007):

- **Strategic Alignment** is the continual tight linkage of organizational priorities and enterprise processes enabling achievement of business goals.
- **Governance** establishes relevant and transparent accountability and decision-making processes to align rewards and guide actions.
- **Methods** are the approaches and techniques that support and enable consistent process actions and outcomes.

- **IT** is the software, hardware, and information management systems that enable and support process activities.
- **People** are the individuals and groups who continually enhance and apply their process-related expertise and knowledge.
- **Culture** is the collective values and beliefs that shape process-related attitudes and behaviors.

In recent years, digitalization has been an omnipresent topic driven by the emergence and adoption of digital technologies, and the fusion of the digital and the physical world. The process impacts humans, companies, the economy, and society as a whole (Gimpel et al. 2018; Legner et al. 2017). Due, in particular, to its impact on companies and their environments, digitalization is understood to have enormous technological, economic, and social effects (Legner et al. 2017; Porter and Heppelmann 2015). Berger et al. (2018), for example, group technological developments into three technology groups; cyber technologies (technologies for sharing data among involved entities), bridging technologies (technologies for sensor-based data collection, actor-based data execution, and self-dependent material agency), and interaction technologies (technologies for transactional, augmented, and natural interaction). Emerging technologies in these areas include, for example, the Internet of Things (IoT), deep learning (DL), and cognitive experts (Berger et al. 2018).

As digitalization impacts humans, companies, the economy, and society, it not only has a significant effect on application areas of BPM but also on the capabilities necessary to manage business processes. Many researchers therefore anticipate transformations in the business processes themselves, as well as in the conceptualization of the BPM domain (Harmon 2017; Kirchmer 2017; Klun and Trkman 2018; van der Aalst et al. 2018). Historically, BPM was largely associated with the analysis of operational activities in factories and physical production systems. However, the discipline evolved such that its capabilities also apply to modern 'production processes' wherein the product is often information rather than a physical entity (van der Aalst et al. 2016). Digital technologies have already shown their potential to transform business processes. For example, new digital technologies heavily influence the production of goods and the provision of services (Colbert et al. 2016; Grossmann 2016; Malone 2007; Porter and Heppelmann 2015). The development of social collaboration platforms and new case management tools has enabled the emergence of virtual teams which can collaborate on knowledge-intensive problems from arbitrary locations (Colbert et al. 2016; Motahari Nezhad and Swenson 2013). Further, the IoT and machine learning (ML) enable organizations to collect and analyze data in order to optimize their interactions with customers, understand customer needs, and tailor processes towards delivering products and services which target these needs (Oberländer et al. 2017; Porter and Heppelmann 2015; Straker et al. 2015).

Despite these and many other examples, little effort has been made to develop a structured approach for assessing the effects that digitalization has on conceptualizations of BPM (Kerpedzhiev et al. 2017). Recker (2014) even criticized that once-novel BPM capability areas 'have too readily been accepted and taken for granted' (2014, p. 12). To address this problem, Kerpedzhiev et al. (2017) conducted a Delphi study with globally renowned experts from industry and academia. The aim was to gain insights about challenges and opportunities in the BPM domain against the backdrop of changes resulting from digitalization. The results of this study were twofold. Firstly, the researchers created an updated version of the BPM capability framework originally developed by de Bruin and Rosemann (2007). This new BPM capability framework accounts for the particularities of the digital age, structuring the capabilities in terms of the core elements, i.e., *strategic alignment*, *governance*, *methods/IT*, *people*, and *culture*. The core elements were drawn from de Bruin and Rosemann (2007), although the two core elements *method* and *IT* were merged. Secondly, the team determined six overarching topics which will be of importance to the BPM domain in the digital age. The updated capability framework allows for a structured comparison of both frameworks, which highlights the impacts of digitalization on the BPM domain. The results show that digitalization significantly impacts several core elements. The newer study also involves substantial changes to the required capability areas, with several new areas added and roughly the same number of existing areas updated. The analysis reveals the need to adapt knowledge and methods, as well as to exploit emerging technologies and innovations from other domains. These findings were condensed into the following six overarching topics addressing the development of the BPM domain in the digital age (Kerpedzhiev et al. 2017):

- **Data:** BPM should capitalize on data and analytical methods to become evidence-driven and facilitate data-intensive business processes.
- **Networks**: BPM should treat business processes as parts of intra- and inter-organizational socio-material networks.
- **Opportunities**: BPM should leverage opportunities including those associated with emerging technologies, new regulations, and demographic shifts.
- **Humans**: BPM should account for the skills, needs, and beliefs of people involved in business processes.

- **Context**: BPM should be customizable and should enable the execution of various types of business processes in diverse contexts.
- **Change**: BPM should enable continuous change, both agile and transformational.

Driven by the need to address the overarching topics related to BPM capabilities in the digital age, this doctoral thesis adds to the body of knowledge about advancements in the BPM domain which have been enabled by technological developments associated with digitalization. The thesis is cumulative and contains seven research papers, which comprise the main research contribution. While the value of all overarching topics is undisputed, the contributions contained in this thesis focus on the topics *data*, *networks*, and *opportunities*. Driven by the technical advancements associated with digitalization, the fundamental question addressed in all the research papers is how digital technologies can be used to create value for companies. Therefore, the research papers included in this thesis take an economic perspective in considering how these technologies can be applied advantageously in the BPM domain. The dissertation is equally relevant for both researchers and practitioners as it deals with the major challenges and opportunities of the BPM domain against a background of advancing digitalization. Figure 1 maps the individual research papers included in this dissertation to the three overarching topics.

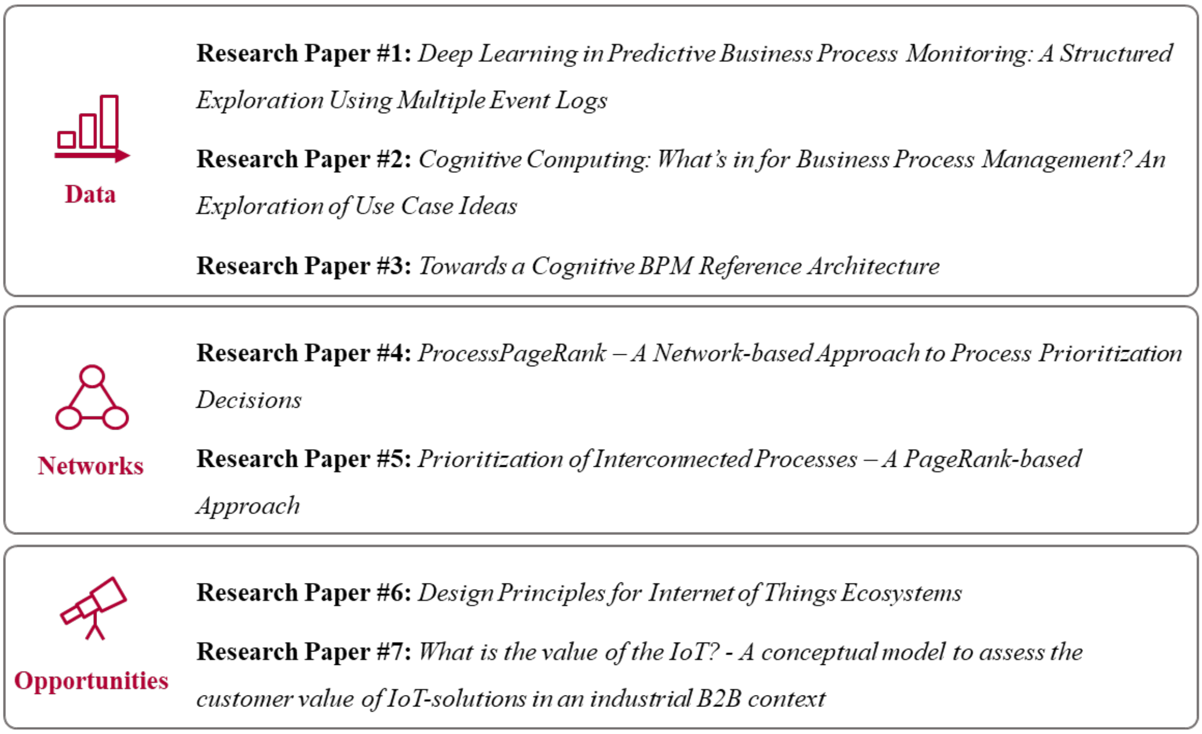


Figure 1: Attribution of the individual research papers to the overarching topics data, networks, and opportunities

Section II is structured in terms of the three overarching topics, introducing the research objectives and the corresponding results. Section II.1 details the leveraging data for evidence-driven

BPM. In this regard, the thesis provides insights as to how new DL approaches can be leveraged for analyzing process data, and under what circumstances these new approaches dominate over classical ML approaches. Section II.2 focuses on treating processes not as a single unit but, instead, as parts of an interconnected process network. The focus is on revealing how knowledge of these relations can used to prioritize processes for improvement. Section II.3 emphasizes the need for an opportunity-focused mindset when exploiting the potential of digital technologies for the business processes and for the BPM domain. This section focuses on the IoT as an exemplary digital technology. Section III concludes with a summary and suggestions for further research. In addition to the references (Section IV), an appendix is attached (Section V) which contains further information relating to all of the included research papers (Section V.1), my individual contribution to these (Section V.2), and the research papers themselves (Section V.3 - V.9).

II Overview and Context of the Research Papers[1]

1 Data

The overarching topic *data* impacts the BPM domain, heavily influencing activities in all phases of the BPM lifecycle (Dumas and Maggi 2015; Evermann et al. 2017; van der Aalst et al. 2012). Decision-making and fault detection in process execution, and the monitoring of performance with a view to process control, improvement, and redesign are examples of such data-driven activities (Meyer et al. 2011; Qin 2014). The collection and analysis of data has long been crucial to the success of BPM activities, but in the past had to be carried out manually (Dumas et al. 2018). Today, the collection of data is largely automated, using process-aware information systems which record events along with additional attributes, e.g., resources or activity outcomes (van der Aalst et al. 2012).

In the context of digitalization, the amount of collected data has grown exponentially thanks to recent developments such as the IoT, wireless communications, mobile devices, and smart manufacturing (Qin 2014). However, the possession of large amounts of data only reveals its benefits through the application of effective data analytics capabilities, which are able to distil data into knowledge (Qin 2014). Gaining knowledge from the increasing amounts of available data is therefore an emerging topic of research in numerous disciplines (Hashem et al. 2015) and sits at the top of many companies' agendas (Lund et al. 2013). Extensive research on data-driven approaches to the analysis of vast amounts of data and the availability of rapidly increasing computational power have led to significant advances in the field of ML. ML refers to the process of machines solving problems using real-world knowledge in order to make human-like decisions without defined rules (Goodfellow et al. 2016). It uses statistical methods to find structural patterns in typically large datasets in a (semi-) automatic manner (Witten et al. 2017). From the extensive research on the topic, a set of sophisticated ML approaches, referred to as DL, has emerged. This yielded a breakthrough in activities such as natural language processing and pattern recognition in images. While most existing approaches use established tactics such as decision trees, random forests (RF), or support vector machines, DL performs exceptionally

[1] This section is partly comprised of content taken from the research papers included in this thesis. To improve the readability of the text, I omit the standard labelling of these citations.

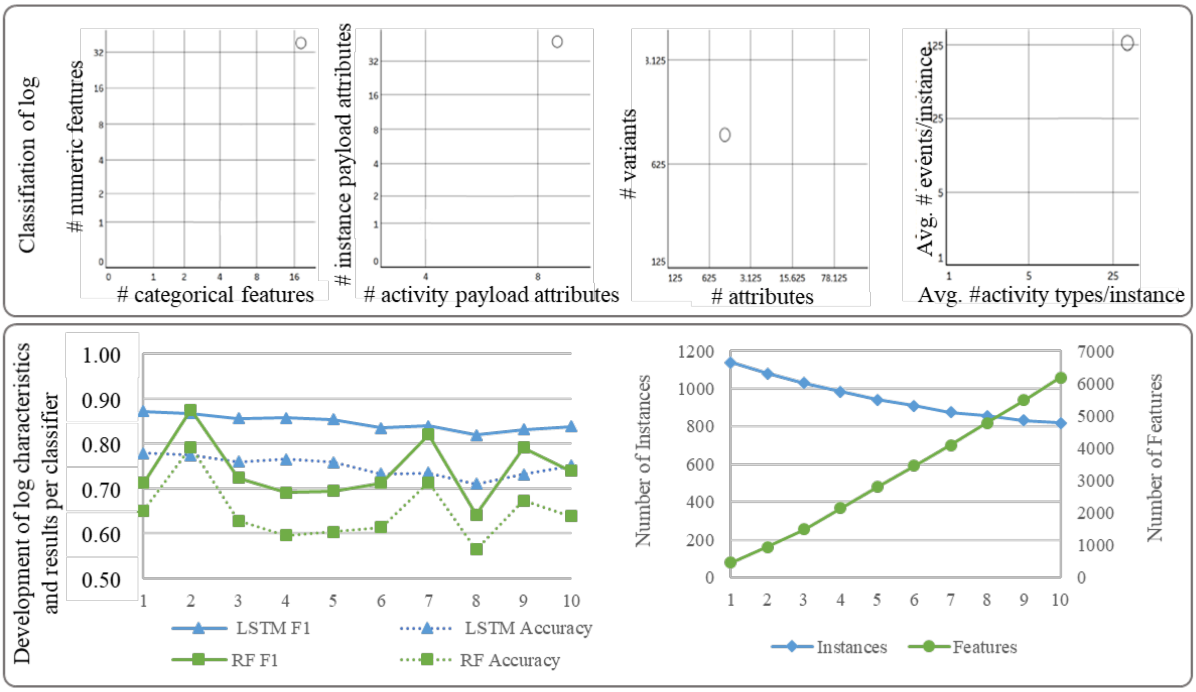
well when it comes to solving increasingly complex problems, e.g., the processing of unstructured data (Goodfellow et al. 2016).

Advancements in ML, as well as in disciplines such as human cognition and computer science, allows for new approaches information systems design (Hurwitz et al. 2015). These information systems no longer focus on automating well-structured tasks. Instead, they utilize ML capabilities in order to analyze text, images, voice, sensors, and videos, and, in doing so, mimic facets of the human brain (Cognitive Computing Consortium 2017). These technological advancements can be bundled under the umbrella term *cognitive computing* (CC), which is seen as an emerging technology tied to the next era of computing (Brant and Austin 2014, 2016; Ardire and Roe 2014). The first two stages of computing, the tabulator and the programming era, were grounded in static and rule-based programs that could only deal with structured and predictable input. CC is said to mark the third transformational shift in computing (Gudivada 2016), envisioning the ability for humans and machines to work hand in hand on unstructured tasks and solving complex problems (Hurwitz et al. 2015).

However, despite promising results in other areas of application, the potential of the technological advancements in DL and CC remains largely unexplored in the BPM domain (Hull and Motahari Nezhad 2016; Qin 2014). Therefore, research papers #1, #2, and #3 deal with the question of how advancements in data-driven approaches can be leveraged in the context of BPM. Research paper #1 focuses on the use of DL for predictive process monitoring, while research papers #2 and #3 address the potential of CC for the BPM domain.

In BPM, most of the early data-driven approaches leveraged data for discovering, monitoring, and improving processes via the extraction of knowledge from process logs, referred to as *process mining* (van der Aalst et al. 2012). However, interest expanded to the use of data-driven approaches for monitoring and controlling in order to gain predictive insights (Grigori et al. 2004). Predictive process monitoring aims to predict the future behavior and performance of process instances – e.g., the remaining cycle time (van der Aalst et al. 2011), compliance monitoring (Ly et al. 2015), sequence of process activities (Polato et al. 2016), or the prioritization of processes for improvement (Kratsch et al. 2017; Lehnert et al. 2018). To do so, most existing approaches use classical ML approaches instead of DL (Evermann et al. 2016), and none use DL to predict process outcomes, although this has already been declared a worthwhile endeavor for future research (Mehdiyev et al. 2017; Evermann et al. 2016). The comparatively rare use of DL, particularly in outcome prediction, reflects a lack of understanding about the conditions under which the use of DL classifiers is sensible and, conversely, under which conditions classical approaches are more suitable. Thus, research paper #1 tackles the question under which conditions DL classifiers should be used for outcome-oriented predictive process monitoring. To address this gap in the knowledge, the paper proposes an experimental setup for comparing the performance of two classifiers – i.e., Long Short-Term Memory Network (LSTM) as an exemplary DL classifier and Random Forest (RF) as an exemplary classical ML classifier – and applied these to arbitrary event logs. In order to ensure a high level of diversity and the conceptual completeness of the event logs, multiple publicly available event logs were examined for deriving constitutive characteristics. The selection of event logs for analysis in the experimental setup is based on this examination, employing a data and a control flow perspective. The results were analzed for each case individually employing well-known metrics (e.g., Accuracy, F-Score, and ROC AUC) revealing the peculiarities of the individual logs.

Figure 2 shows the results for an exemplary log. The top section shows the log classification, the middle section the accuracy and F1 scores for each classifier and each time step after which the classification was carried out. Additionally, Figure 2 shows the number of instances and features taken into account when building the classifier in each time step. The bottom part of Figure 2 shows key measures per classifier aggregated over all time steps.



	Accuracy		F-Score		ROC AUC	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
RF	0.6473	0.0627	0.7402	0.0656	0.6128	0.0581
LSTM	0.7498	0.0206	0.8470	0.0162	0.7799	0.0195

Figure 2: Results for analysis of an exemplary log

Building on the results for each log in every time step, the paper reports on a cross-case analysis, which exposed similarities and differences linking the evaluation metrics with the derived log classifications. The cross-case analysis leads to four overarching conclusions, relevant to respond on the research question:

- LSTM generally outperforms RF in terms of accuracy.
- LSTM produces a more balanced performance.
- LSTM requires a longer setup time to provide reliable classifiers.
- The time stability of LSTM is considerably better.

From a theoretical perspective, the paper adds to the body of knowledge regarding the application of DL in BPM. From a managerial perspective, the paper helps process managers to understand the potential of different classes of ML approaches, and supports decision making about the conditions under which DL approaches should be favored over classical ML approaches.

With the shift towards the information society, knowledge-intensive processes (KiPs), sometimes also referred to as non-routine or agile processes, have become increasingly important.

Nowadays, KiPs are cornerstone for value creation in many key business areas such as research, engineering, and service management (Mundbrod and Reichert 2017; Di Ciccio et al. 2015). Unlike transactional processes, KiPs are characterized as non-predictable, emergent, and goal-oriented, and often rely on human experience, judgement, and creativity (Marjanovic and Freeze 2012; Mundbrod and Reichert 2017). As CC shares key features with KiPs, Hull and Motahari Nezhad (2016) introduced Cognitive BPM (CBPM); a field of research which aims to support both transactional processes and KiPs via the use of CC. CBPM involves those facets of BPM wherein CC offers new developmental opportunities, either by changing the ways in which data is processed or presented, or by changing the ways that processes are designed. However, research on CBPM is still rather scarce.

In order to demonstrate the potential of CBPM, and to stimulate further research, research paper #2 investigates potential use cases for CC in the context of BPM. As there is still no commonly-accepted definition of CC, a literature review was conducted in order to develop a working definition. The results of this review found that CC can be described using four constitutive characteristics: interaction (i.e., natural communication between humans and machines, as well as among humans), context awareness (i.e., identification and extraction of contextual information from structured and unstructured data on a large scale), reasoning (i.e., generation, testing, and assessment of hypotheses based on context information and past learnings), and learning (i.e. continuous expansion of the knowledge base – via the incorporation of learning from prior decisions and reasoning – in order to derive a working definition for CC and its constitutive characteristics). Integrating these constitutive characteristics, CC can be defined as an *umbrella term for new problem-solving models which strive to mimic the cognitive capabilities of the human mind via autonomous reasoning and learning based on incomplete structured and unstructured contextual data, and via natural interactions with humans and machines.*

To help researchers and practitioners in identifying and articulating CBPM use cases, the paper proposes a framework based on the derived constitutive characteristics and the working definition for CC. The framework integrates the most important classes of problems addressed by CC with central activities of the BPM lifecycle. To illustrate the use of the framework, a series of CBPM use cases has been developed and categorized. Table 1 shows the analysis framework, including short titles of the developed CBPM use cases.

	Cognitive Computing Problem Classes

Activities of the traditional BPM lifecycle	Solutions to knowledge-intensive problems (A)	Human-Computer Interaction (B)	Human Collaboration (C)
Definition & Modelling (1)	- Identify process models from unstructured data - Design and adaption of configurable process models considering organizational context - Suggestion of, and translation between, process modelling approaches	- Interactive process design support	- Visualization of process models considering different stakeholders - Support in process design collaboration
Implementation & Execution (2)	- Dynamic resource allocation at runtime - Automatic execution or suggestions of next best task at runtime	- Interactive task assignment assistant at runtime - Support in decision-making at runtime - Dynamic suggestions of collaboration at runtime	- Support in handling processes with participants of different backgrounds
Monitoring & Controlling (3)	- Automatic anomaly and deviant behavior detection at runtime	- Conversation-like process monitoring queries - Interactive user feedback considering user characteristics and process instance	
Optimization & Implementation (4)	- Proactive identification of process improvement opportunities	- Identification of need for training	- Support of collaboration between process managers and participants

Table 1: Analysis framework of Cognitive Computing in the context of BPM

Table 1 shows promising CBPM use cases, but as of today, actual implementations, as well as guidance on the implementation of CBPM use cases, remain scarce. Prior to the implementation of a CBPM use case, the CBPM system in question needs to be appropriately designed, which requires significant efforts, e.g., regarding the specification of requirements (Maciaszek 2001). In software development, a well-established method of reducing these efforts is to base the design of the CBPM system on established standards, which are conceptualized in a reference architecture (RA). RAs facilitate the software development process in multiple ways by, e.g., providing a standardized view of the desired system, identifying required components for the desired system, and ensuring interoperability between components, which may be provided by different vendors (Angelov and Grefen 2008). Despite the existence of numerous promising CBPM use cases, guidance on implementation in the form of a CBPM RA is still lacking. Therefore, research paper #3, addresses the question of what the design of a CBPM RA should look like. To tackle this question, a CBPM RA is developed, which serves as a foundation in the implementation of CBPM use cases. Further, the RA also serves as an initial approach to the standardization of CBPM architectures, in that it facilitates and guides further advances in the CBPM domain. The design of the RA is based on an integration of existing RAs from both BPM and CC, and integrates all BPM lifecycle phases and all problem classes from the CC domain. The RA consists of four components, namely *collect*, *comprehend*, *create*, and *compose*. The collect component bundles relevant data sources. The comprehend component is central to the CBPM RA in that it is responsible for finding answers to the questions asked by the user. The create and compose components serve as interfaces between the user and the system, and vice versa. Specifically, the create component process questions asked by the user in order to create valid input for the comprehend component. The compose component uses the answer from the comprehend component and prepares the answer so as to make it understandable for the user. The resulting CBPM RA is shown in Figure 3.

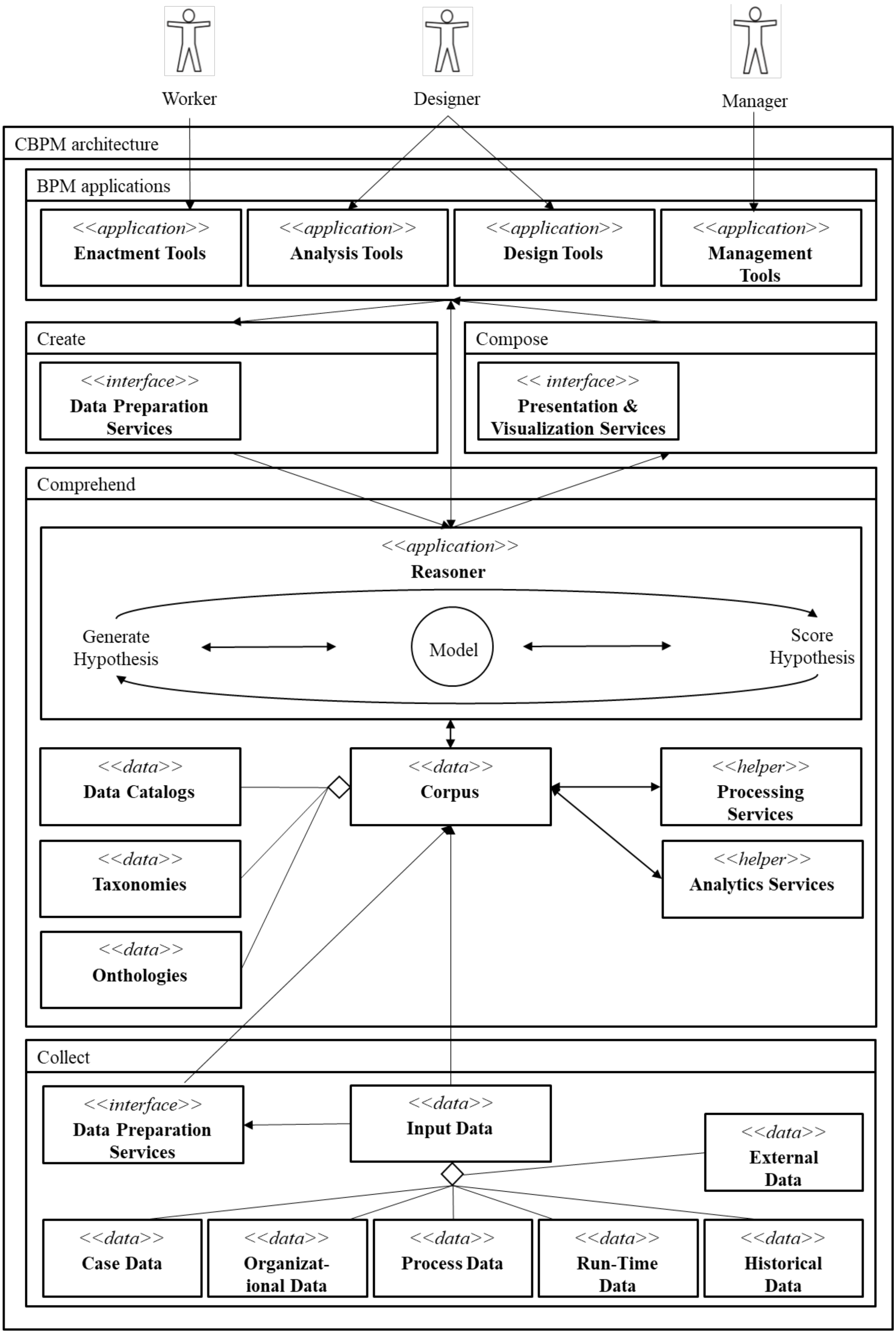


Figure 3: Cognitive BPM Reference Architecture

In terms of the overarching topic of data, this thesis provides insights regarding the application of DL approaches in BPM. The results indicate that, despite the popularity of ML approaches for process outcome predictions, DL approaches perform better than classical ML approaches in many application scenarios, leading to more accurate predictions and therefore allowing more precise decision making for the process stakeholders. Research papers #2 and #3 shed light on the potential of CC in the BPM domain and address obstacles which may hinder the effective adoption of the technology. Specifically, research paper #2 delivers a clear definition of CC based on constitutive characteristics derived from the literature, together with a framework for the classification of CBPM use cases. Research paper #3 builds on these results and enriches knowledge of CBPM with an RA that facilitates the implementation of CBPM use cases.

2 Networks

The overarching topic of *networks* deals with viewing processes not as a single unit but rather as parts of process networks which account for intra- and inter-process dependencies, within or even across organizational boundaries (Kerpedzhiev et al. 2017). The integration of digital technologies into production processes allows for the comprehensive interconnectedness of production systems. This offers competitive advantages (e.g., higher flexibility and efficiency) and also leads to highly interconnected intra- and inter-organizational networks (Iansiti and Lakhani 2014). When such production processes are analyzed, interconnectedness needs to be explicitly taken into account (Häckel et al. 2018). This increasing interconnectedness is not only evident in production processes, but is also relevant to many aspects of BPM, dependencies between multiple instances of the same process, different processes, and processes crossing organizational boundaries need to be taken into account (Kratsch et al. 2017). Beyond BPM-specific reasons, the need to consider interconnectedness and to identify central nodes in networks has been recognized and addressed in many disciplines (e.g., project portfolio management, network analysis, enterprises architecture management) (Landherr et al. 2010; Probst et al. 2013; Winter and Fischer 2007). Although it is known that processes influence one another on different levels, if dependencies are modelled, it is usually only for descriptive purposes, e.g., in process model repositories and business process architectures (BPAs) (Dijkman et al. 2016; La Rosa et al. 2011; Malinova et al. 2014).

The drawbacks of ignoring dependencies among processes especially become evident in process improvement. Despite the importance of process improvement, more than 60 % of the corresponding initiatives are reported to fail (Chakravorty 2010; Harmon 2016). Often, this is due to the fact that companies focus on the wrong processes or on too many processes at once (Ohlsson et al. 2014). Therefore, companies rely heavily on effective process prioritization that takes dependencies between processes into account (Manderscheid et al. 2015). In general, improving one process affects the performance of other processes if the later processes rely on the outcome of the former (Leyer et al. 2015). It may thus be reasonable to prioritize processes with a low stand-alone need for improvement if many other processes depend on their outcome. If process interconnectedness is ignored, decisions about prioritization are likely to suffer and corporate funds may be allocated inefficiently.

Despite this knowledge, process prioritization approaches which consider the need to improve both individual processes and their interconnectedness are still lacking. Thus, research papers

#4 and #5 deal with the question of how processes can be prioritized based on their individual need for improvement and interconnectedness. The papers propose an artefact called the *ProcessPageRank* (PPR) which takes the performance of individual processes and the relationships between multiple processes into account, and thus responds to the need for a process prioritization that accounts for interconnectedness. The performance of individual processes is measured via an *individual need for improvement index* and is based on performance indicators in accordance with the dimensions of the Devil's Quadrangle. The PPR considers the factors *cost*, *time*, and *quality* from the Devil's Quadrangle, as *flexibility* can be covered via the others (Ray and Jewkes 2004). An algorithm based on Google PageRank adjusts the processes' individual need for improvement so as to reflect the relationships between multiple processes. This produces the network-adjusted *need for improvement index* for each process. The relationships between processes are determined using a process map and are captured in a process network which focuses on use-relations. Use-relations indicate that a process (the using process) requires the output of another process (the used process) to continue or complete its execution. The *dependence intensity* thereby indicates how strongly the performance of the using process depends on the used process. Figure 4 shows the transformation of a process map into a process network, as well as the required annotations which serves as input for the PPR.

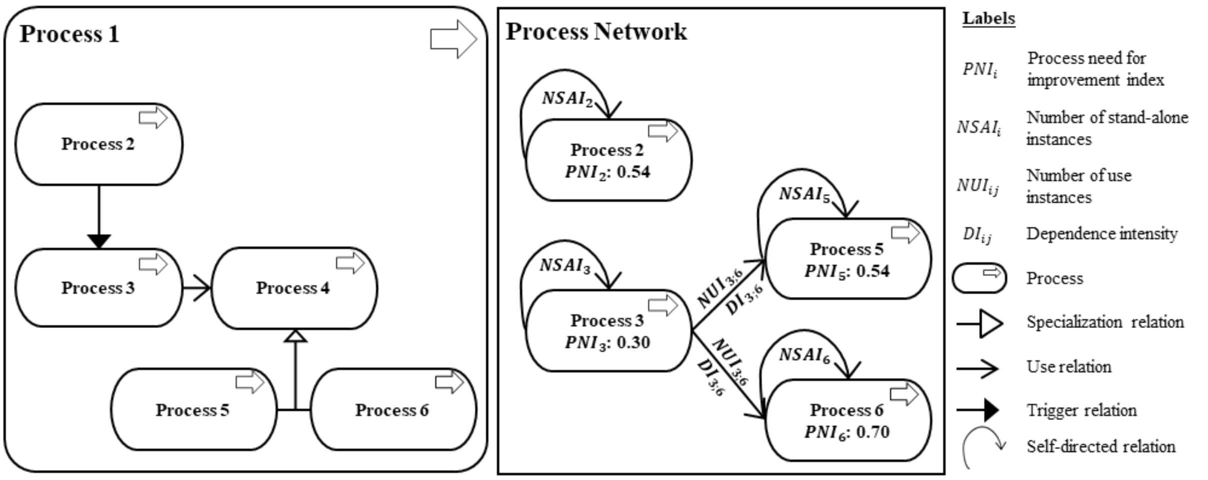


Figure 4: Transformation of a process map into a process architecture

The PPR is the first approach to account for process interconnectedness when prioritizing processes for improvement. The PPR also is the first approach to apply the mature knowledge on centrality measures to process decision-making in general, and to process prioritization in particular. By delivering an approach for taking process interconnectedness into account, the PPR adds to the prescriptive knowledge on process prioritization and sheds light on the overarching topic of networks.

3 Opportunities

The key drivers of digitalization are rapid advancements in digital technologies, i.e., "products or services that are either embodied in information and communication technologies or enabled by them" (Lyytinen et al. 2016). Significant investments in the development of digital technologies lead to ever-shorter time-to-market cycles and ever-faster commoditization (Urbach and Röglinger 2018). Digital technologies have a significant effect on companies in particular, as well as society as a whole, leading to great *opportunities* for new business models, business processes, and products and services (Berger et al. 2018). Digitalization, on the one hand, allows companies to take advantage of opportunities afforded by digital technologies, but, on the other hand, demands profound changes within organizations, which must adapt to changing requirements (Matt et al. 2015; Turber et al. 2014). When engaging in digitalization, companies need to address various challenges such as the need to deal with rapid technological innovation, adapt business rules, redesign organizational structures and business processes, and/or adapt the company's culture (Ashurst et al. 2008; Markus and Benjamin 1997; Matt et al. 2015; Turber et al. 2014). Despite high expectations, many companies are failing to realize the potential of digitization (Gimpel and Röglinger 2015; Hirt and Willmott 2014).

The shift towards a digitally empowered economy also impacts on the business processes of companies, and, so too, the companies' corresponding BPM capabilities (Jesus and Rosemann 2017). Digital technologies have a substantial effect on work, which provides great opportunities and pose great challenges (Matt et al. 2015). In the BPM domain, the basic idea of investigating the impact of technological advancements is a familiar concept, already present in the seminal works of Davenport (1993) and those of Hammer and Champy (1993). However, research in general is mostly driven by problem-centric approaches, i.e., those which attempt to find solutions for previously identified problems (Papachroni et al. 2016). In contrast, research which considers how to systematically exploit opportunities arising from new inventions remains scarce (Röglinger et al. 2018b). Therefore, companies need an opportunity-centric mindset and a structured approach as they further examine the potential and impact of digital technologies on their processes and their BPM capabilities (Jesus and Rosemann 2017). When it comes to developing a structured approach via which to explore the potential of digital technologies for the BPM domain, researchers developed ambidextrous BPM as an organizational capability allowing constant and agile organizational change in a rapidly evolving business environment (Rosemann 2014; Kohlborn et al. 2014). Drawing on the general ideas of organizational ambidexterity, ambidextrous BPM maintains capabilities for simultaneous *process exploration* and *exploitation*. While *exploitation* strives for the careful refinement of existing processes and allows only small changes, *exploration* aims at the radical redesign of processes (Röglinger et al. 2018a). Discovering the potential that digital technologies hold when it comes to processes, as well as for the BPM domain, is an activity related to *exploration*.

As stated in the introduction, emerging digital technologies can be categorized into three groups: cyber technologies, bridging technologies, and interaction technologies (Berger et al. 2018). The IoT is a representative of the bridging technologies and is regarded as one of the most disruptive digital technologies currently available (Berger et al. 2018; Barrett et al. 2015; Porter and Heppelmann 2015). The IoT fosters the fusion of the digital and the physical worlds by equipping objects with sensors, actuators, computing logic, and connectivity. Therefore, the IoT turns physical objects from passive tools into active smart things, enabling them to act increasingly autonomously from humans (Oberländer et al. 2017; Porter and Heppelmann 2015; Rosemann 2014; Yoo et al. 2012). This not only allows the enhancement of products and services, but also leads to the emergence of new business models such as product-as-a-service or product sharing (Porter and Heppelmann 2015), promising huge economic potential.

From a BPM perspective, the IoT offers numerous possibilities for enhancing both the processes themselves and the BPM domain (Janiesch et al. 2017; redhat 2016). The introduction of smart things offers opportunities for data collection, efficiency gains, revitalization of established or even depreciated products, and new forms of process automation (Janiesch et al. 2017; Del Giudice 2016). With the increasing push of computing intelligence into edging technology, smart things not only collect data, but rather compose a new class of actors capable of performing single tasks or automating entire processes. The intelligent combination of sensors and the potential to integrate collected data enables a shift from procedure automation, wherein strict rules determine the process flow, to goal-oriented process automation, wherein the process flow is dynamically adjusted in accordance with current information (redhat 2016; Janiesch et al. 2017). The McKinsey Global Institute predicts the economic potential to be up to USD 11 trillion per year by 2025 (Dobbs et al. 2015; Manyika et al. 2015). However, as of today, the number of promising IoT implementations is limited, and positive effects lag behind expectations (Cisco 2017; InfoQ 2017; McKinsey 2017). To realize the predicted economic potential, a deeper understanding of the technology is needed in order to integrate it into the BPM domain.

Thus, research papers #6 and #7 shed light on how to overcome existing hurdles blocking the effective adoption of the IoT. Research paper #6 argues that significant barriers to IoT adoption include security concerns, a lack of interoperability, and a lack of large-scale projects beyond individual smart things. Proprietary and domain-specific IoT-solutions dominate the market, hampering the realization of anticipated network effects (McKinsey 2015; InfoQ 2017; Podnar Žarko et al. 2016). Researchers and practitioners agree that a breakthrough may come with the use of IoT ecosystems (IoTEs) which consist of a platform as a common core and companies and individuals who collaborate via this platform to realize a focal value proposition (Adner 2017; Mazhelis and Tyrvainen 2014; Weill and Woerner 2015). IoTEs allow for sharing information and applications, analyzing and combining data, and utilizing synergies, thus enabling new business models and unlocking network effects (Moore 1993; Iansiti and Levien 2004; Weill and Woerner 2015). In IoTEs, smart things and related value propositions are subject to constant refinement and optimization as a result of collaboration and competition among ecosystem participants (Porter and Heppelmann 2015). Furthermore, the integration of standalone systems into interconnected system-of-systems (i.e., ecosystems) promotes positive network effects (Metcalfe 1995), as more stakeholders provide higher than proportionate collaboration opportunities. Thus, expanding the IoT from standalone smart things to IoTEs fosters value co-creation and innovation. Despite these promising expectations, there is broad consensus that no IoTE has yet been successfully established (Podnar Žarko et al. 2016; InfoQ 2017; Cisco 2017; Sinha and Park 2017). Even worse, owing to the magnitude of design options, there is also disagreement about how IoTEs should be established (Cisco 2017; Sinha and Park 2017). Against this backdrop, research paper #6 poses the research question: *Which design principles apply to IoTEs?*

The paper contributes to a nascent IoTE design theory by proposing a catalogue of design principles (DPs). These act as guidelines for designing a real-world instantiation based on justificatory knowledge derived from business ecosystems, software ecosystems, and the IoT. The paper adopts Schermann et al.'s (2009) approach, deriving requirements, sub-requirements, issues, and DPs. The requirements acts as operational goals for the chosen design. These requirements are operationalized in sub-requirements, which, in turn, can be achieved by "resolving" issues. Issues can be resolved by implementing the DPs. Figure 5 illustrates the results by providing an overview of requirements, sub-requirements, issues, and DPs for IoTEs.

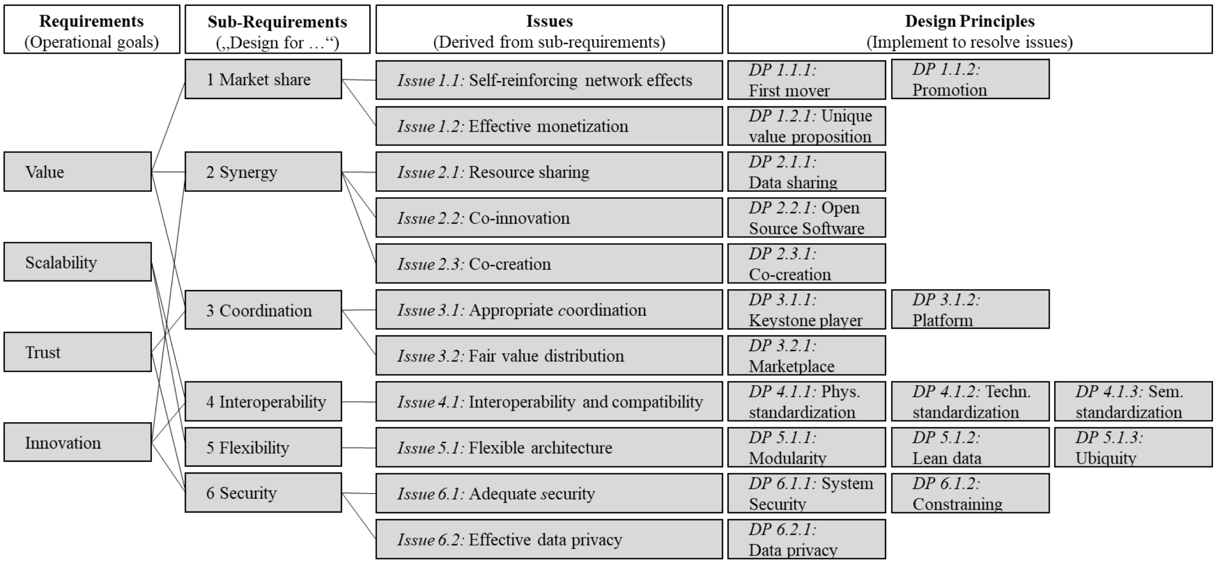


Figure 5: Overview of (Sub-) Requirements, Issues, and DPs for IoTEs

Hence, the paper contributes to the emerging IoTE design theory, by contributing a catalog of DPs which can be applied to IoTEs and foster these to perform well on operational requirements. From a practical perspective, the paper bridges the gap between technological and business considerations about IoTEs, helping practitioners in understanding the pontential of IoTEs and allowing them to leverage the developed DPs for building a business model within an IoTE.

Besides the absence of IoTEs, and cultural obstacles (Mejtoft 2011), commercialization in general and effective monetization in particular are critical barriers to market success (Bilgeri and Wortmann 2017). In a business-to-business (B2B) context, IoT-solutions enable smart processes which lead to increased flexibility, quality, and/or efficiency, leading to overall gains in performance and the reduction of wasteful activities (Ashton 2009; Fähnle et al. 2018; Fantana et al. 2013; Weinberger et al. 2016). In a business-to-customer (B2C) context, IoT-solutions provide smart products and services which are integrated into the individual's private processes, generating functional value comparable to that generated in the B2B context, as well as non-functional value such as emotions, health, or safety (Almquist et al. 2016; Fähnle et al. 2018). When it comes to monetization, companies usually take a cost-perspective rather than a value-perspective. Irrespective of the application context, companies usually determine a one-off price for physical products by adding a margin to the production costs, known as 'cost-plus-pricing'. IoT-solutions, however, combine physical products with digital services, leading to constitutive characteristics specific to IoT-solutions, i.e., high and recurrent development costs but near-zero costs for replication, distribution, and individual use (Fichman et al. 2014). The constitutive characteristics of IoT-solutions and physical products differ substantially, and, in the case of IoT-solutions, value creation tends to originate from the digital service rather than the physical product, spanning multiple stakeholders and generating various direct as well as indirect benefits (Del Giudice 2016; Sheth 2016). Therefore, traditional cost-plus-pricing is not applicable to IoT-solutions as it disregards monetization potential by neglecting the actual value generated for the customer and for associated stakeholders. Instead, IoT-solutions demand value-based monetization, building on a sound conceptual understanding and using a structured approach to assess the value generated for the customer (Kindström 2010). Therefore, research paper #7 poses the following research question: *What is a structured approach to assess the customer value of IoT-solutions from an industrial company's perspective?*

In order to address this question, the research paper proposes a model for the value assessment of IoT-solutions, which consists of a conceptual framework and corresponding value levers. The framework approaches the value-creation of IoT-solutions from the perspective of an industrial company, i.e., the business supplier (BS), offering an IoT-solution to another industrial company, i.e., the business customer (BC), who in turn either uses the IoT-solution to enhance internal processes, to improve the products and services externally offered to its consumers (C), or both. The framework therefore encompasses an exemplary business-to-business-to-consumer (B2B2C) value chain. This represents the minimum configuration including all relevant stakeholders, but is easily extendable, e.g., by adding additional business customers. Despite the focus on the creation of value for the BC, the framework purposefully extends the scope towards the C in order to capture all relevant value categories, which directly or indirectly affect the BC's value perspective. Figure 6 illustrates the conceptual framework.

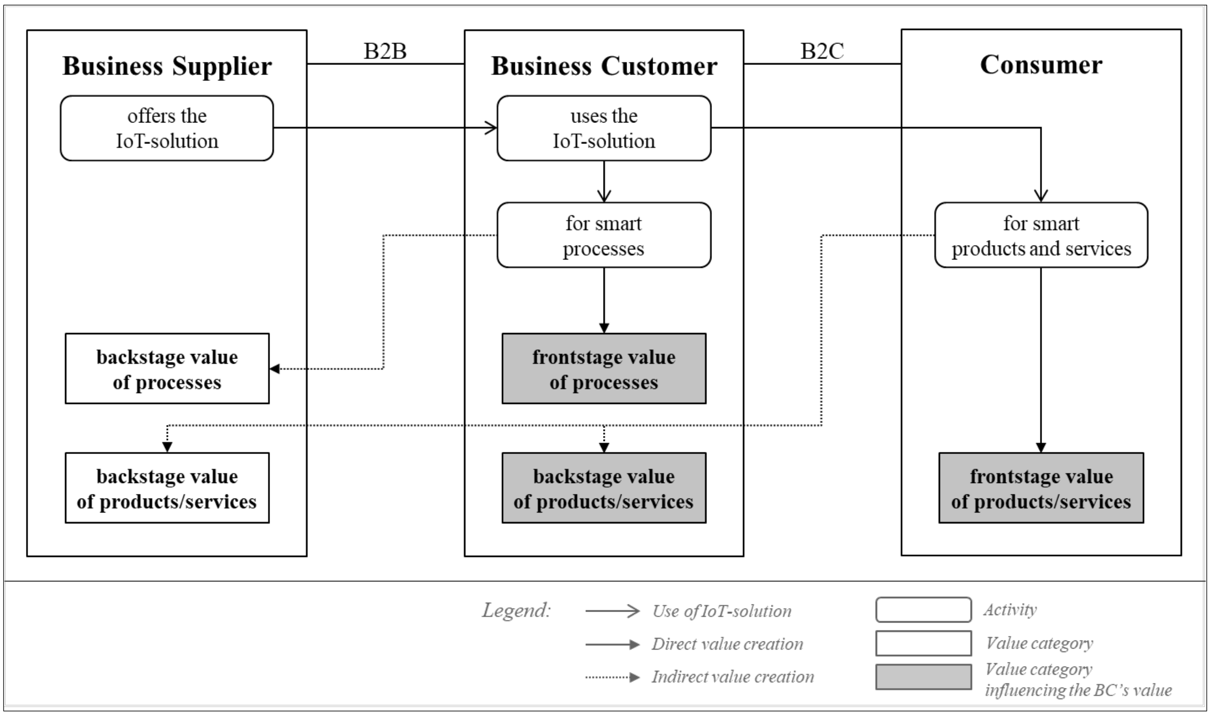


Figure 6: Conceptual framework for assessing the value of IoT-solutions

The framework reveals the need to examining the whole value chain when assessing the value creation of an IoT-solution, rather than focusing only on the immediate customer. Moreover, the framework emphasizes the need to include the frontstage and backstage value of processes, and products and services. The framework therefore contributes to the justificatory knowledge on the IoT and helps practitioners to accurately assess the value of IoT-solutions as a crucial prerequisite of monetization.

Based on the framework, the paper develops three value lever trees for determining the frontstage value for the BC and the C as well as the backstage value for the BC. These value lever trees are based on a structured literature review and guide practitioners when determining the value of an IoT-solution.

As stated, the IoT holds great potential to improve processes and the BPM domain, allowing for, e.g., increased automation, more accurate data collection, a reduction in errors, and increases in overall efficiency (Janiesch et al. 2017). Yet, despite this potential, actual revenue remains below expectations. Therefore, research papers #6 and #7 provide insights as to how companies can harness the potential of the IoT for BPM. Research paper #6 details how an IoT ecosystem can be designed in order to foster its success. Research paper #7 proposes a model for determining the value of IoT-solutions in an industrial context, which provides a basis for value-based pricing instead of cost-plus pricing.

III Conclusion[2]

1 Summary

Due to its marked technological, economic, and social effects, digitalization heavily impacts business processes and the BPM domain as a whole. Through the rapid developments of new digital technologies, digitalization presents many opportunities. Yet, it also presents challenges which need to be addressed. Examining the BPM domain from a capability perspective, Kerpedzhiev et al. (2017) identified six overarching topics which need to be addressed: *data*, *networks*, *opportunities*, *humans*, *context*, and *change*. In order to shed light on the impact digitalization has on the BPM domain, this doctoral thesis contributes to the first three of the six overarching topics. Firstly, the collection and analysis of data has always played an important role in BPM, but companies need to develop new ways of using this collected data. Secondly, processes need to be viewed as parts of networks involving intra- and inter-process dependencies, rather than as isolated units of analysis. Thirdly, companies need to develop an opportunity-centric mindset in order to exploit the potential of newly developed digital technologies for the BPM domain.

On the topic of data, Section II.1 shows how data-driven approaches can be leveraged in the context of BPM. Research paper #1 investigates when and how DL approaches deliver more accurate and reliable process outcome predictions than classic ML approaches. The results show that DL approaches outperform classic approaches when event logs originate from processes with multiple variants (e.g., knowledge-intensive processes), when event logs show imbalanced classes, and when event logs provide large amounts of features. In turn, DL approaches do not deliver better results when few instances are recorded in an event log, or when little payload data is attached to activities and instances. Research papers #2 and #3 investigate the impact of cognitive computing on the BPM domain. Research paper #2 derives constitutive characteristics of cognitive computing (i.e., interaction, context awareness, reasoning, and learning) and proposes a working definition. Based on this groundwork, the paper then proposes an analytical framework for deriving and structuring Cognitive BPM use cases. It also presents

[2] This section is partly comprised of content taken from the research papers included in this thesis. To improve the readability of the text, I omit the standard labelling of these citations.

a first set of use case ideas, developed using the analytical framework. Research paper #3 draws on these results to propose a Cognitive BPM reference architecture.

Regarding the topic of networks, Section II.2 first addresses an overarching issue: the reconceptualization of processes as parts of process networks. This section also considers how process interconnectedness can be taken into account when prioritizing processes for process improvement. Research papers #4 and #5 thus develop the PPR as an artefact which ranks processes in terms of their network-adjusted need for improvement. The network-adjusted need for improvement takes into account each process's individual need for improvement, building on multiple aspects of process performance (i.e., cost, quality, time). Their interconnectedness is captured via use relations in the process network. The PPR adds to the prescriptive knowledge on process prioritization, in that it is the first approach to apply centrality measures to process prioritization, and can also help practitioners to prioritize specific processes for improvement.

Digitalization provides individuals, companies, and society with numerous opportunities. Taking advantage of these opportunities often involves overcoming the various obstacles which accompany the adoption of new digital technologies. With this in mind, Section II.3 provides a structural analysis of how companies can navigate the obstacles which accompany IoT-solutions. Research paper #6 argues that issues such as security concerns, a lack of interoperability, and a lack of large-scale projects beyond individual smart things can all be overcome by establishing IoT ecosystems. The paper therefore proposes a set of design principles which foster the establishment of such IoT ecosystems. Research paper #7 takes an economic perspective, arguing that although commercialization and effective monetization are critical barriers to the market success of IoT-solutions, current literature fails to provide adequate guidance on their value assessment. In response to this problem, the research paper provides a conceptual model for assessing the customer value of IoT-solutions, which is understood to be a crucial pre-requisite for effective monetization. The conceptual model consists of a framework and corresponding value levers. The framework builds on an exemplary and extendable value chain (B2B2C) focusing on the perspective of an industrial company as the solution provider. The value levers operationalize the framework and provide guidance as to how the value of an IoT-solution can be assessed. The research paper contributes to the conceptual knowledge of the IoT, and supports practitioners in their attempts to assess IoT value potential for effective monetization.

2 Future Research

As with all research, the results presented in this doctoral thesis are beset with limitations. However, as the individual research papers already elaborate on the limitations of the presented results, this section focuses on an aggregated overview of the thesis' limitations, and looks toward further research on advancing the BPM domain in the digital age.

Fristly, Kerpedzhiev et al. (2017) proposed six overarching topics relevant for advancing the BPM domain in the digital age, yet only three of these topics are covered in this thesis. In terms of the three overarching topics that are addressed, the research presented is far from exhaustive. Therefore, further extensive research is needed in order to provide deeper insights into the three overarching topics addressed in this thesis and those three topics that are excluded.

Secondly, digital technologies are developing at a rapid pace, and the full potential of digitalization remains largely untapped. While the results included in this thesis are based on current, cutting-edge literature, future developments might affect the validity of the research results. For example, in terms of the results presented in research paper #1, the performance of one of the featured algorithms may be affected by the future development of new algorithms, possibly raising the advantages of one algorithm above the other. Therefore, the research results need to be frequently reviewed and critically challenged in light of new developments in digital technologies. Future research could pick up the results included in this thesis and review them in the light of the future state-of-the-art.

Thirdly, the research in this thesis takes a design-oriented perspective to address arbitrary challenges associated with the use of digital technologies in the BPM domain. This perspective is reflected in the results. The design of such studies usually involves abstracting from the real world in order to reduce complexity and allow for the development of comprehensive models. The abstraction from the real world is captured in the assumptions, which explicitly list the simplifications made. Despite the fact that each of the assumptions that feature in the research papers has been carefully formulated and critically questioned, there is nonetheless a risk that the subsequent results overlook relevant, real world factors. These risks are taken into account in the validation approaches used to evaluate the results. These approaches range from experimental setups to expert interviews to prototypical implementation. However, a design-oriented approach to the development and evaluation of new results can only provide a first indication of their potential. Behavior-oriented approaches and empirical investigations are indispensable next steps to validate the relevance of the results in real-world settings, and so serve as starting point for future research.

In conclusion, this doctoral thesis contributes to existing knowledge about the impact of digitalization on the BPM domain. It does so by generating innovative and relevant results via the aggregation and elaboration of prior knowledge. The thesis supports practitioners in their attempts to understand the impact that digitalization has on the BPM domain, and provides guidance as to how digital technologies may be used to advance selected BPM capabilities.

It is my hope that researches and practitioners can use the research presented in this thesis to address the challenges, and exploit the opportunities, associated with digitalization in the BPM domain.

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V Appendix

1 Index of Research Papers

Research Paper #1: Deep Learning in Predictive Business Process Monitoring: A Structured Exploration Using Multiple Event Logs

Kratsch, Wolfgang; Manderscheid, Jonas; Röglinger, Maximilian; Seyfried, Johannes (2018): Deep Learning in Predictive Business Process Monitoring: A Structured Exploration Using Multiple Event Logs. *Not yet published*.

Research Paper #2: Cognitive Computing: What's in for Business Process Management? An Exploration of Use Case Ideas

Röglinger, Maximilian; Stelzl, Simon; Seyfried, Johannes; zur Muehlen, Michael (2017): Cognitive Computing: What's in for Business Process Management? An Exploration of Use Case Ideas. In: *Proceedings of the Business Process Management Workshops at the BPM Conference*, Barcelona, Spain.

Research Paper #3: Towards a Cognitive BPM Reference Architecture

Kratsch, Wolfgang; Röglinger, Maximilian; Seyfried, Johannes (2018): Towards a Cognitive BPM Reference Architecture. *Not yet published.*

Research Paper #4: ProcessPageRank – A Network-based Approach to Process Prioritization Decisions

Lehnert, Martin; Röglinger, Maximilian; Seyfried, Johannes; Siegert, Maximilian (2016): ProcessPageRank – A Network-based Approach to Process Prioritization Decisions. *Proceedings of the 23rd European Conference on Information Systems (ECIS)*, Münster, Germany.

Research Paper #5: Prioritization of Interconnected Processes – A PageRank-based Approach

Lehnert, Martin; Röglinger, Maximilian; Seyfried, Johannes (2018): Prioritization of Interconnected Processes – A PageRank-based Approach. *In: Business & Information Systems Engineering (BISE)*, 60(2), pp. 95-114.

Research Paper #6: Design Principles for Internet of Things Ecosystems

Blume, Maximilian; Röglinger, Maximilian; Seyfried, Johannes; von Wachter, Victor (2018): Design Principles for Internet of Things Ecosystems. *Not yet published.*

Research Paper #7: Towards effective monetization of the Internet of Things - A conceptual model to assess the customer value of IoT-solutions in an industrial context

Baltuttis, Dennik; Häckel, Björn; Oberländer, Anna Maria; Röglinger, Maximilian; Seyfried, Johannes (2018): Towards effective monetization of the Internet of Things - A conceptual model to assess the customer value of IoT-solutions in an industrial context. *Not yet published.*

2 Individual Contribution to the Featured Research Papers

This thesis is cumulative, and seven research papers comprise the main body of the work. All of these papers involved multiple researchers. Thus, in this section, I will detail the project settings and my individual contribution to each paper.

Research paper #1 was developed within a team of four researchers. The team jointly conceptualized and elaborated the paper's content. Together, we developed the idea of categorizing event logs according to their characteristics. I was primarily responsible for conceptualizing the data preparation, and for implementing the corresponding software prototype, which was needed in order to rehash the input for the RF and LSTM in a consistent manner. I also supported the development of the classifiers, which was mainly undertaken by one of the other co-authors. The single- and cross-case analysis were joint efforts involving all four members of the team. Throughout, I was substantially involved in each part of the project.

Research paper #2 was written with three co-authors. Based on an initial idea provided by one of the co-authors, the team jointly conceptualized and elaborated the paper's content. I was primarily involved in the development of the constitutive characteristics and the corresponding definition of CC. Based on the results, the author team jointly developed and categorized the featured use cases. Together with one co-author, I presented and discussed the findings at the BPM conference in Barcelona, Spain.

Research paper #3 was written as a follow-up to research paper #2. The research project was conducted with two co-authors. However, there was a switch in authors, as one of the co-authors of the preceding paper dropped out and another co-author joined the team. In this research project, we incorporated the feedback given in response to my talk in Barcelona, and built the new artefact based on these results. I was the leading author in this research project and therefore developed the central premise of the paper. Further, I was largely responsible for the development and elaboration of the research method, and for the reference architecture. Although the paper was, to a large extent, my own work, the other co-authors were involved in each part of the project and helped to discuss and improve the paper.

Research paper #4 was developed in a team of four authors. The team jointly conceptualized and elaborated the structure and content. Together, we conducted validation regarding the requirements to integrate the interconnectedness of processes into process prioritization decisions, and described how to transform business process architectures into process networks. I was mainly responsible for developing the mathematical model by adjusting the Google PageRank algorithm. I also implemented the prototype capable of calculating the PPR for an arbitrary process network.

Research paper #5 is a follow-up to research paper #4. However, the research project was conducted in a team of three authors, as one of the co-authors of research paper #4 had dropped out. In this research project, we incorporated the feedback collected when presenting research paper #4 at the European Conference on Information Systems (ECIS) in Münster. We also further developed the process-specific need for improvement as a multi-dimensional construct, substantiated the interconnectedness of processes, and improved our evaluation of the project. Members of the author team were equally involved in advancing the concepts regarding individual need for improvement, and interconnectedness. I was particularly involved in the adaption of the mathematical model, and in the implementation of the research results into the corresponding prototype. I also played a key role in evaluating the concepts we developed.

Research paper #6 was written together with three co-authors. All co-authors jointly developed the basic concept for the paper and elaborated the content. I was particularly involved in deriving and structuring the design principles. I also took responsibility for the revision of the paper for resubmission. Throughout, I was substantially involved in each part of the project.

Research paper #7 was developed in a team of five authors. All co-authors jointly developed the basic concept of the paper and elaborated the content. Together with one of the co-authors, I conducted the structured literature review. I was also primarily responsible for developing and elaborating the research method. Overall, the authors made equal contributions to the content of the paper, and I was substantially involved in each part of the project.

3 Research Paper #1: Deep Learning in Predictive Business Process Monitoring: A Structured Exploration Using Multiple Event Logs[3]

Authors: Kratsch, Wolfgang; Manderscheid, Jonas; Röglinger, Maximilian; Seyfried, Johannes

Submitted to: Business & Information Systems Engineering (BISE)

Extended Abstract

Predictive business process monitoring aims to forecast the future behavior and performance of business processes. Among other things, it can be used to identify problems before they occur, or to re-allocate surplus resources before they are wasted. Today, many predictive monitoring techniques are available. Although deep learning (DL) has yielded several breakthroughs for data-driven applications, most predictive monitoring techniques still build on classical approaches which are based on restrictive assumptions. So far, it is not yet understood under which conditions it is sensible to apply DL in predictive process monitoring. This may be an obstacle preventing the wider adoption of DL in business process management.

We addressed this research gap based on the principles drawn from case study research (Yin 2018). To do so, we performed a structured exploration and comparison of classical ML approaches and DL-based approaches based on five publicly available event logs. As for classical ML approaches, we employed Random Forests (RFs) and Support Vector Machines (SVMs). As for DL-based approaches, we employed Recurrent Neural Networks (RNNs), representing a generalist DL approach, and Long Short Term Memory Networks (LSTMs), representing a DL approach matching the specifics of processes. To ensure a holistic view allowing analytical generalizability of our results, we ensured the collection of diverse event logs distinguishing between a data perspective and a control flow perspective. As for our structured comparison, we built classifiers for each approach after the first ten activities of every event log.

The analysis of the results was twofold. First, we analysed the results for each log individually, interpreting key metrics such as accuracy, precision, recall, F-Score, and the area under the receiver operating characteristic curve. Second, we performed a cross-case analysis to reveal analytically transferable results. Doing so, we identified five key findings:

[3] At the time of the publication of this thesis, this essay is in the review process of a scientific journal. Thus, I provide an extended abstract that covers the essay's content.

- DL classifiers generally outperform classical ML classifiers with respect to accuracy.
- In contrast to ML classifiers, DL classifiers are able to cope with a high number of process variants.
- The time stability of DL classifiers is considerably better than that of ML classifiers.
- LSTM produces a more class-balanced performance compared to all other classifiers.
- Regarding data-intensive processes with many variants, LSTM shows a substantial outperformance compared to RNN.

From a research viewpoint, our paper contributes to the body of knowledge regarding process outcome prediction and predictive process monitoring. From a managerial viewpoint, our paper provides guidance about the conditions under which DL approaches ought to be favored over established ML approaches and supports process managers to comprehend the capability of various classes of ML approaches. In spite of the fact that classical ML approaches generally showed to be less complex in terms of implementation and computation, there are conditions under which our picked DL classifiers (i.e., RNN and LSTM) conveyed better results.

References

Yin Robert (2018): Case study research and applications: Design and methods. Sage Publications, Los Angeles, London, New Dehli, Singapore, Washington DC, Melbourne.

4 Research Paper #2: Cognitive Computing: What's in for Business Process Management? An Exploration of Use Case Ideas

Authors: Röglinger, Maximilian; Stelzl, Simon; Seyfried, Johannes; zur Muehlen, Michael

Published in: Proceedings of the Business Process Management Workshops at the BPM Conference, (2017).

Abstract: Cognitive Computing promises to fundamentally transform corporate information processing and problem solving. Building on latest advances in cognitive, data, and computer science, Cognitive Computing aims to deliver autonomous reasoning and continuous learning under consideration of contextual insights and the natural interaction of humans and machines. Cognitive Computing is expected to offer significant application opportunities for business process management (BPM). While first studies have investigated the potential impact of Cognitive Computing on BPM, the intersection between both disciplines remains largely unexplored. In particular, little work has been done on identifying Cognitive BPM use cases. To address this gap, we develop an analysis framework that aims to assist researchers and practitioners in the development of Cognitive BPM use case ideas. This framework combines the most significant problem classes addressed by Cognitive Computing with central activities of the BPM lifecycle. We also used the framework as foundation of explorative workshops and report on the most interesting cognitive BPM use cases ideas we discovered.

Keywords: Cognitive Computing, Business Process Management, Cognitive BPM, Use Cases

5 Research Paper #3: Towards a Cognitive BPM Reference Architecture

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Submitted to: ACM Transactions on Management Information Systems (TMIS)

Extended Abstract

With the shift towards the digital age, knowledge-intensive business processes, characterized as non-predictable and emergent, have become a cornerstone for modern value creation. The Business Process Management (BPM) domain of today offers a strong set of tools and methods for supporting transactional processes, but since transactional processes and knowledge-intensive processes substantially differ in their characteristics, the tools and methods can only be applied to a limited extent. In recent years, Cognitive Computing (CC) has emerged as a novel computing paradigm sharing its determining features with knowledge-intensive processes. While first studies explored the potential impact CC on BPM, the intersection between both disciplines remains largely unexplored. There are some initial ideas about what BPM use cases can support, but there is still a lack of successful implementations. A structured approach to fostering the systematic application of CC in BPM can help overcome this barrier.

To address this research gap, we developed a Cognitive Business Process Management Reference Architecture (CBPM RA). The CBPM RA intersects reference architectures from the BPM and the CC domain, providing a first approach for standardizing CBPM architectures as well as facilitating and guiding further advances in the CBPM domain. Our research approach was guided by the method for the development of an RA proposed by Galster and Avgeriou (2011) extended with details from Angelov et al. (2012) and Nakagawa et al. (2014). We designed CBPM RA with the goal of facilitation in order to provide guidelines for the future design of systems. As for the design strategy, we aimed at a preliminary RA being of use to multiple organizations. The resulting RA consists of components and connectors, and is described in a semi-detailed, semi-formal fashion. We evaluated our CBPM RA based on a prototypical implementation of a CBPM use case enlivened by Röglinger et al. (2018). The goal was to enable process managers to design process models based on spoken natural language as sole input. The prototype was implemented as an instantiation of the previously designed CBPM RA.

The designed CBPM RA can deal with use cases in all phases of the BPM lifecycle (definition and modeling, implementation and execution, monitoring and controlling, plus optimization and implementation) as well as in all CC problem classes (solution of knowledge-intensive problems, human-computer interaction, human collaboration) as it integrates one of the most

well-known BPM RAs (van der Aalst 2013) as well as one CC RA (Hurwitz et al. 2015). We demonstrated applicability via the implementation of one CBPM use case.

We believe that the proposed CBPM RA advances the understanding of the potential of CC technologies in the BPM domain. The paper provides guidance regarding the implementation of CBPM use cases and calls for further research in close collaboration with industry to probe into the feasibility of our CBPM RA and, thereby, help explore the novel technological opportunities for BPM enabled by CC.

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6 Research Paper #4: ProcessPageRank – A Network-based Approach to Process Prioritization Decisions

Authors: Lehnert, Martin; Röglinger, Maximilian; Seyfried, Johannes; Siegert, Maximilian

Published in: Proceedings of the 23rd European Conference on Information Systems (ECIS), 2015.

Abstract: Deciding which business processes to improve first is a challenge most corporate decision-makers face. The literature offers many approaches, techniques, and tools that support such process prioritization decisions. Despite the broad knowledge about measuring the performance of individual processes and determining related need for improvement, the interconnectedness of processes has not been considered in process prioritization decisions yet. So far, the interconnectedness of business processes is captured for descriptive purposes only, for example in business process architectures. This drawback systematically biases process prioritization decisions. As a first step to address this gap, we propose the ProcessPageRank (PPR), an algorithm based on the Google PageRank that ranks processes according to their network-adjusted need for improvement. The PPR is grounded in the literature related to process improvement, process performance measurement, and network analysis. For demonstration purposes, we created a software prototype and applied the PPR to five process network archetypes to illustrate how the interconnectedness of business processes affects process prioritization decisions.

Keywords: Business Process Decision-Making, Business Process Architecture, Decision Support, PageRank, Business Process Improvement, Business Process Prioritization

7 Research Paper #5: Prioritization of Interconnected Processes – A PageRank-based Approach

Authors: Lehnert, Martin; Röglinger, Maximilian; Seyfried, Johannes

Published in: Business & Information Systems Engineering (BISE), 2017.

Abstract: Deciding which business processes to improve is a challenge of all organizations. The literature on business process management (BPM) offers several approaches that support process prioritization. Sharing the individual process as unit of analysis, these approaches determine the processes' need for improvement mostly based on performance indicators, but neglect how processes are interconnected. So far, the interconnectedness of processes is only captured for descriptive purposes in process model repositories or business process architectures (BPAs). Prioritizing processes without catering for their interconnectedness, however, biases prioritization decisions and causes a misallocation of corporate funds. What is missing are process prioritization approaches that consider the processes' individual need for improvement and their interconnectedness. To address this research problem, we propose the ProcessPageRank (PPR) as our main contribution. The PPR prioritizes processes of a given BPA by ranking them according to their network-adjusted need for improvement. The PPR builds on knowledge from process performance management, BPAs, and network analysis – particularly the Google PageRank. As for evaluation, we validated the PPR's design specification against empirically validated and theorybacked design propositions. We also instantiated the PPR's design specification as a software prototype and applied the prototype to a real-world BPA.

Keywords: Business process management, Network analysis, PageRank, Business process architecture, Process interconnectedness, Process network, Process prioritization

8 Research Paper #6: Design Principles for Internet of Things Ecosystems

Authors: Blume, Maximilian; Röglinger, Maximilian; Seyfried, Johannes; von Wachter, Victor

Submitted to: Electronic Markets.

Extended Abstract

The Internet of Things (IoT) is widely regarded as one of the most disruptive technologies on the market. Yet, the often-proclaimed positive effects attributed to the IoT fall behind expectations. Significant barriers of IoT adoption are missing interoperability, security concerns, and a lack of large-scale projects beyond individual smart things. In fact, business thinking has not kept up with technological progress. Ever more researchers and practitioners argue that the establishment of IoT ecosystems (IoTEs) can push the IoT toward breakthrough. However, IoTEs are still low on theoretical insights. Thus, this paper aims to bridge technology and business considerations by compiling a catalogue of IoTE design principles (DPs) that extend extant prescriptive knowledge on IoTEs and guide practitioners in relevant IoTE design choices.

To do so, we followed the design science research paradigm proposed by Gregor and Hevner (2013) developing a catalogue of DPs that define the structure, organization, and functioning of the design product (Gregor and Jones, 2007). We built our DPs based on mature knowledge from the fields of business and software ecosystems (BEs and SEs), which have been existing for many years and subject to various research projects. As IoTEs show substantial similarities to BEs and SEs, we transfered this knowledge to IoTEs, while catering for specifics of IoT. Therefore, we conducted an extensive literature research on BEs, SEs, IoTEs, and IoT platforms in order to identify possible DPs. We clustered the identified DPs by assigning them to operational requirements and sub-requirements. We evaluated our DPs regarding applicability and usefulness in the context of a IoTE from the smart home sector.

Following our research approach, we identified a total of 18 DPs fostering the success of IoTEs. We structured these DPs by assigning them to four operational requirements (value, scalability, tust, innovation), which follow a cause-effect-relation, meaning that the implementation of one DP has a positive effect on the respective operational requirement. Acknowledging the large gap between the DPs and operational requirements, we added a layer of six sub-requirements (market share, synergy, coordination, interoperability flexibility, and security) bridging this gap, whereas one DP is connected to one sub-requirement, but one sub-requirement can be connected to multiple operational requirements. We evaluated the applicability and usefulness

of our DPs based on the IoTE "Google Home". The evaluation showed that a promising IoT solution aiming to become a leading IoTE implemented the majority of our DPs, which attests applicability of our DPs. Moreover, we found evidence for IoTE requirements being positively influenced by the implementation of our DPs, we validated usefulness of our DPs and demonstrated how the DPs can be used as analytical lens for investigating a real IoT solution.

Our DPs add to the prescriptive knowledge aiming at the development of a design theory for IoTEs by providing literature backed knowledge on the successful development of an IoTE. From a managerial viewpoint, this paper integrates technological and business considerations regarding IoTEs helping practitioners to gain a wholistic view. Especially against the backdrop of the highly diverse IoTE market with over 450 platforms, practitioners can evaluate and compare IoTEs based on our DPs to position themselves accordingly.

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9 Research Paper #7: Towards effective monetization of the Internet of Things - A conceptual model to assess the customer value of IoT-solutions in an industrial context

Authors: Baltuttis, Dennik; Häckel, Björn; Oberländer, Anna Maria, Röglinger, Maximilian; Seyfried, Johannes

Submitted to: Electronic Markets.

Extended Abstract

The Internet of Things (IoT) is among the most disruptive technologies associated with enormous economic potential. However, actual revenues from IoT-solutions remain lower than expected, and effective monetization is a barrier to market success. Due to high development costs, low costs of replication, and value creation across stakeholders, IoT-solutions demand value-based monetization rather than traditional 'cost-plus pricing'. As current literature fails to provide guidance, we pose the following research question: What is a conceptual model to assess the customer value of IoT-solutions from the perspective of an industrial company?

To address this research question, we developed a model consisting of a framework as well as corresponding value levers identified in a structured literature review. In order to develop our model, we followed a three-step approach: I) Development of the framework, II) operationalization of the framework, and III) real-world demonstration and evaluation. Regarding I), we developed a framework for understanding the customer value of IoT-solutions in an iterative process, capturing relevant value categories per stakeholder along an exemplary B2B2C value chain. Regarding II), we operationalized our framework by providing value levers influenced by IoT-solutions which we identified in a systematic literature review and structured along our framework. Regarding III), we validated criteria such as completeness, fidelity with real world, and robustness based on five interviews with different companies from the field of industrial manufacturing. Furthermore, to validate general applicability and usefulness of the value levers, we conducted an in-depth examination and an initial quantification of value potentials for two IoT-solutions provided by two of the interview partners.

Our framework shows an exemplary value chain with three relevant stakeholders, namely: the business supplier (BS) who provides the IoT-solution, the business customer (BC), who uses the IoT-solution, and the (end-)consumer (C), who consumes the product provided by the BC. The BC thereby uses the IoT-solution either for improving the products and services provided

to the C or to improve his processes. Focusing on value levers influencing the BC's value, we identified three relevant value categories, namely (1) the frontstage value of smart processes for the BC (BC uses IoT-solutions provided by the BS for improving its own processes), (2) the frontstage value of smart products and services for the C (C consumes products and services that are embodied or enhanced by IoT-solutions which the BC sources from the BS) and, (3) the backstage value of smart products and services for the BC (BC indirectly gains value from continuous remote interactions, data collection, and analytics provided by the IoT-solution). We operationalized the framework by identifying and structuring relevant value levers for each value category identified in a systematic literature review.

With our research, we provide a two-fold contribution in response to our research question. First, we provide a framework for assessing the value potential of an IoT-solution in an exemplary B2B2C value chain from the perspective of the BC. Second, we propose a value lever approach allowing a structured analysis of value creation. From a theoretical viewpoint, our work contributes to the conceptual knowledge of the IoT. From a practical viewpoint, we provide guidance for effective monetization and value-based pricing of IoT-solutions from the perspective of an industrial company.