Advanced Process Digitalization, Compliance, and Automation

Dissertation

zur Erlangung des Grades eines Doktors der Wirtschaftswissenschaft

der Rechts- und Wirtschaftswissenschaftlichen Fakultät

der Universität Bayreuth

Vorgelegt

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Tag der mündlichen Prüfung:	02. Februar 2021

"There is nothing either good or bad but thinking makes it so."
William Shakespeare, Hamlet (Act II, Scene 2)

Auckland, Augsburg, Bayreuth, Berlin, Bournemouth, Brisbane, Dörfles-Esbach, Feuchtwangen, Hamburg, Hof, Laupheim, Manchester, Mitterteich, Munich, Nagold, Naperville, Neustadt b. Coburg, Petershausen, Rabat, Rehau, Selb, Stuttgart, St. Louis, Sydney, Ulm, and Wellington – Thank you so much for being part of my doctoral journey and for continuously supporting me.

Also, a big thank you to the dude and my supervisor, Max, particularly for your stringent, canonic, and tangible way of imparting knowledge as well as experience – I always appreciated it. It was a pleasure to work and research with you.

Abstract

Digitalization brings with it ongoing socio-technical change, including new and innovative ways of interacting and technological developments. In response, both academia and industry must continually rethink and improve methods, approaches, structures, and applications if they are to thrive in the digital age. In particular, the corporate success of organizations relies on their ability to react appropriately to changing conditions. Business process management (BPM) traditionally helps organizations to ensure corporate success. BPM has recently also offered methods to explore and innovate business processes, leading to the creation of new products or services. BPM enriched by digital solutions enables new business processes and value propositions and transforms those already in existence. Digital transformation also impacts, among other things, management styles, individual behavior, compliance, and automation capabilities. Consequently, BPM must continuously adjust to react appropriately to new developments driven by the digital age. Yet, BPM emphasizes the need to understand the influence of the digital age before enacting change. Such understanding is seen as a crucial prerequisite to adequately address the changing needs.

Developed in response to such shift, this cumulative doctoral thesis consists of five research articles that provide insight into BPM in the digital age and provide guidance for both industry and academia by reconceptualizing BPM's capabilities. Furthermore, the in-depth investigation of two capability areas (i.e., *"Process Compliance Management"* and *"Advanced Process Automation"*) addresses challenges and opportunities considered important from an expert perspective. Firstly, this thesis presents an overview of the impact of changing conditions and an updated capability framework. Secondly, this thesis examines *"Process Compliance Management"* in terms of process deviance and presents an innovative strategy for creating positive process deviations. Thirdly, the incorporation of mobile devices into manufacturing highlights the potential of *"Advanced Process Automation"*.

The theoretical foundation of the thesis is a capability framework consisting of five core elements and 30 equally distributed capability areas (research article #1). In response, a framework consisting of 33 reasons for deviance applies a management perspective to explain why process deviations occur (research article #2). Following this, positive process deviance provides the analytical lens in an experiment that uses digital nudging to leverage positive deviations as a starting point for process improvements (research article #3). This thesis then reveals how mobile devices automate production processes (research article #4). Finally, the incorporation of smartphones demonstrates their potential as data collectors and facilitators of predictive maintenance and decision support technology (research article #5).

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I. Introduction[1]

The ongoing trend towards digitalization leads to transformational change for individuals, organizations, and society (Legner et al. 2017). Socio-technical change and new technologies – including social collaboration platforms, robotics, artificial intelligence, the Internet of Things (IoT), and blockchain – alter routines and business processes (Gimpel et al. 2018; Legner et al. 2017). The current speed of development cycles is remarkable, and there is little chance of a slowdown. Unsurprisingly, the Gartner Hype Cycle for Emerging Technologies has detailed over 100 different digital technologies that can unlock new opportunities for organizations, improving – or creating radically new –value propositions (Gartner 2020). This fast-moving environment leads to rapidly changing customer demands, increased regulation, and greater levels of competitive pressure (Legner et al. 2017). Yet it is only by adapting to changes that companies are able to keep pace with their competitors, provide value to their customers, and remain vital (Kagermann et al. 2013; Legner et al. 2017; Porter and Heppelann 2014).

In this digital age, we are living in what has been termed a 'VUCA world' (Bennett and Lemoine 2014), that is, one characterized by volatility, uncertainty, complexity, and ambiguity. To leverage these characteristics, organizations have to manage the complexity of various entities, including technology, regulation, and culture (Davenport and Westerman 2018; Gimpel et al. 2018). As many managers have observed when asked to reflect on the general challenges and opportunities of the digital age, a careful balance of time and resource investments is key (Davenport and Westerman 2018; Denner et al. 2018). Yet, in many cases, efforts to incorporate digital technologies are focused on improvements in flexibility, automation, efficiency, sustainability, or cost reduction (Kang et al. 2016; Lasi et al. 2014). The incorporation of digital technologies leads to a stronger fusion of the digital and the physical world, which suggests increasing awareness of the big picture of corporate transformation (Matt et al. 2015). For example, connecting enterprise information systems with production machines results in more efficient production processes (Kang et al. 2016). In a further step, the incorporation of IoT and the Industrial IoT (IIoT) devices equipped with sensors, actuators, and internet connectivity (Oberländer et al. 2018) provides recommendations for actions or the automatic control of IT systems, production machines, and other devices. New control flows open new sources of data that enable novel methods for analytics, control, decision support, and management. Advanced data analysis facilitates decision support calculations (Mobley 2002;

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

Schleichert 2017; Swanson 2001) that can decrease costs by 25% (Gu et al. 2017). However, such incorporations require updates to the underlying business and to production processes (Gimpel et al. 2018).

Processes are always affected, as these occur everywhere within an organization whenever products or services are created for internal or external consumers (Dumas et al. 2018). Organizations need to focus on affected processes in order to gain from the digitalization. As the related discipline, business process management (BPM) aims to realize operational quality, either by performing inside-out activities to highlight the potential for improvements or by performing outside-in activities to explore and radically innovate new products and services (Dumas et al. 2018; He and Wong 2004; Rosemann 2014). In general, "BPM is the art and science of overseeing how work is performed in an organization to ensure consistent outcomes and to take advantage of improvement opportunities" (Dumas et al. 2018, p. 1). From a management perspective, a holistic consideration of all processes of an organization (van der Aalst 2013) using an inside-out (i.e., driven by observable problems) and outside-in (i.e., driven by opportunities) activities is necessary (Rosemann 2014). Activities included in established BPM lifecycles comprise the identification, design, implementation, analysis, and improvement of business processes (Dumas et al. 2018). These activities address multiple process types, including business, support, and management processes (Armistead 1999; Dumas et al. 2018). The improvement of business processes is considered to be one of the phases capable of adding the most value (Dumas et al. 2018; van der Aalst et al. 2016). The overall goal of process improvement initiatives – similar to digitalization – is to decrease processing times and costs and increase flexibility and quality (Reijers and Mansar 2005; van der Aalst et al. 2016). Many methods have been developed to help stabilize organizations via improvements (Gross et al. 2019; Harmon 2018; vom Brocke et al. 2020). However, methods for proactively leveraging innovations and new value propositions are equally important (Grisold et al. 2019; Rosemann 2014, 2020). In addition to established methods, such as Total Quality Management (Walton 1988), Lean Management (Chen and Taylor 2009), Six Sigma (van der Aalst et al. 2016), and Business Process Reengineering (Al-Mashari et al. 2001) vom Brocke et al. (2020) identified more than 100 methods which mainly focus on the inside-out perspective. One approach that balances an inside-out with an outside-in perspective is to analyze and institutionalize positive processes deviations. On the one hand, process managers analyze internally available process data to address non-compliant processes to ensure consistent outcomes. On the other hand, external entities can trigger deviations. For example, customers, competitors, or suppliers who impose special requirements. Employees must deviate from definitions to fulfilling the externally triggered requirements. The analysis of positive deviance embraces both perspectives to find an appropriate balance. Hence, positive deviance offers abundant opportunities for process improvements and innovations (König et al. 2019; Mertens et al. 2016). Broadly speaking, process deviance is the intentional or unintentional behavior of process participants who do not fulfill process definitions in individual tasks, sub- or entire processes (Alter 2014; Depaire et al. 2013; Dumas and Maggi 2015; König et al. 2019; Mertens et al. 2016). Such deviations can have either positive (constructive) or negative (detrimental) effects on the processes' performances (Alter 2014; Andrade et al. 2016; König et al. 2019).

In addition to lifecycle models and business process improvement initiatives, capability frameworks can assist process managers by bundling the crucial capability areas an organization needs for the holistic management and implementation of business processes (Poeppelbuss et al. 2015; vom Brocke and Rosemann 2015). One aim is to be able to capture the status quo of the implementation of BPM capabilities in an organization. The status quo is the basis for fit/gap analysis, the derivation of roadmaps, and the prioritization of BPM investments (vom Brocke and Rosemann 2015). De Bruin and Rosemann (2007) have proposed a now widely-utilized capability framework consisting of 30 capability areas structured around six core elements. These six core elements – Strategic Alignment, Governance, Methods, Information Technology, People, and Culture – include five capability areas per factor and offer a comprehensive toolbox for BPM (de Bruin and Rosemann 2007; vom Brocke and Rosemann 2015). More than 1,000 publications have referred to the framework in the last decade, indicating high acceptance among BPM researchers. The de Bruin and Rosemann (2007) framework ensures consistent process outcomes referring to BPM lifecycle phases. It proposes capability areas that incorporate the lifecycle phases in the core elements of Methods and Information Technology, underlining the status of the phases. However, the rapid pace of digitalization currently characterizing the development of new technologies and trends is likely to overtake BPM efforts to provide state-of-the-art and relevant capabilities (Klun and Trkman 2018). With the emergence of digitalization and the so-called digital age, it has become evident that BPM requires a holistic update of its capability areas. Recker (2014) encourages updates of capability frameworks, arguing that established capability areas "have too readily been accepted and taken for granted" (Recker 2014, p. 12). Yet, in addition to updating established capability frameworks, a deeper understanding of how digitalization affects BPM is now required. Therefore, the central research question of this cumulative doctoral thesis is as follows: *How does digitalization impact business process management and how can suitable artifacts be designed to take compliance and automation aspects into account?*

To answer this central research question, it is split into three sub-research questions: (1) Which challenges and opportunities drive digitalization for BPM and its capabilities? (2) How can a compliance perspective combined with digital technologies enable process improvements? and (3) How can mobile devices automate and leverage decision support in processes? Explorative and design-orientated research approaches address the three sub-research questions to answer the central research question. The advantage of these research approaches is to extend the body of knowledge by descriptive and prescriptive knowledge that is instantly usable. According to the VUCA world, the fast creation of artifacts seemed promising in order to enable time- and data-intensive confirmatory or theory-based studies. Before tangible artifacts following an ADR approach are created, the understanding of the impact of digitalization is explored by Delphi studies and an experiment.

Accordingly, this cumulative doctoral thesis extends extant knowledge by contextualizing BPM within the digital environment. The doctoral thesis consists of five individual research articles located at the intersection of BPM, the challenges and opportunities of the digital age, process deviance, and advanced automation, which address the central research question altogether. The basis is an explorative study that investigates future challenges and opportunities for BPM in the digital age, which goes some way towards updating de Bruin and Rosemann's (2007) framework. Two capability areas – "*Process Compliance Management*" and "*Advanced Process Automation*" – are further analyzed to answer the second and third sub-research questions. Both capability areas feature in the wide-ranging core element Methods / Information Technology.

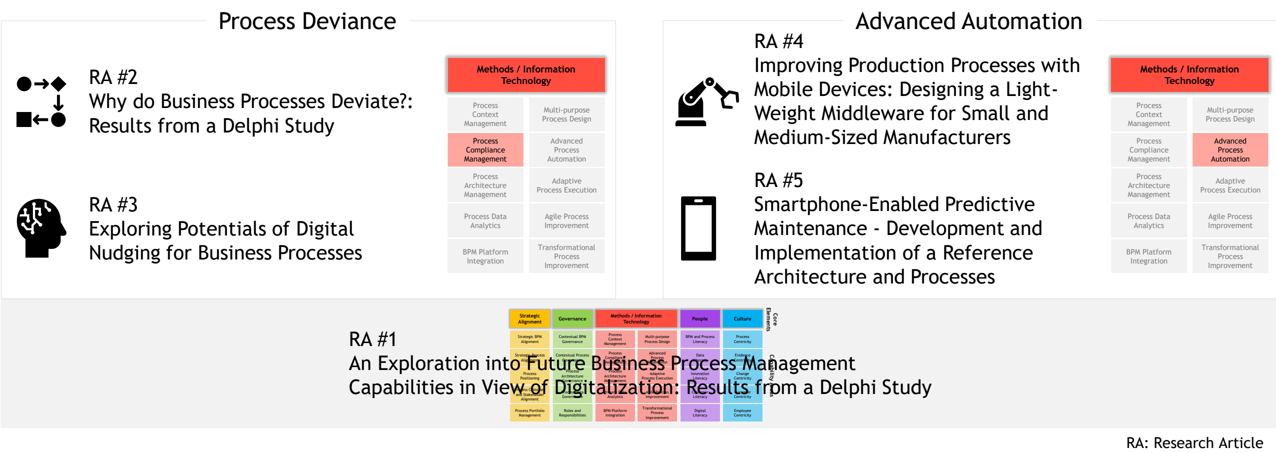

Figure 1. Assignment of the research articles to the topics structuring this cumulative doctoral thesis

Figure 1 shows how the individual research articles build on the holistic conceptualization of BPM in the digital age and propose directions for the management of process deviance and advanced automation. The same structure can be found in Section II.

Firstly, this thesis presents the foundation aim of reconceptualizing BPM in the digital age in terms of an updated BPM capability framework. It holistically examines challenges and opportunities for BPM in the digital age. This preparatory step resulted in five core elements (i.e., strategic alignment, governance, Methods / Information Technology, people, and culture), which entail 30 equally allocated capability areas for managing business processes in the digital age (Section II.1 – including research article #1). The capability framework advances the traditional understanding of BPM.

Secondly, using insights from Section II.1, the thesis addresses an important challenge and opportunity, evaluated by experts, by presenting explorative insights into the capability area *“Process Compliance Management”*. A Delphi study was carried out to investigate process deviance and its underlying causes from a management perspective (Section II.2 – including research article #2). These findings advance the current understanding of process deviations and their relative importance in routine and nonroutine process. Following these explorative results, this thesis presents results from an experimental investigation of how positive deviations can be realized via digital nudges, alternating the choice architecture of process participants (Section II.2 – including research article #3). In an experiment involving 473 participants, the study assesses the effectiveness of digital nudging in encouraging process participants to deviate positively. The experimental results further advance the potential of constructive non-compliance, representing another source of process improvements.

Thirdly, the thesis provides insights from two action design research (ADR) projects, evaluated in practice-based settings. Each of these projects provides a solution to another important, previously-classified challenge and opportunity, and details a corresponding capability area, namely *“Advanced Process Automation”*. Mobile devices, particularly smartphones, are used to increase process efficiency. The first project presents the results of an industry 4.0 project which facilitates the improvement of production processes at small and medium-sized manufacturers via the incorporation of mobile devices (Section II.3 – including research article #4). Five related design principles for the successful application of industry 4.0 provide support for academics and practitioners involved in similar initiatives at the process level. The second project presents a reference architecture for smartphone-based predictive maintenance implementations (Section II.3 – including research article #5). Overall, the design knowledge advances the reasonable incorporation of mobile devices to leverage process automation.

Finally, Section III summarizes the key insights and provides avenues for future research. In addition to the publication bibliography in Section IV, an appendix is attached in Section V, including additional information on all research articles (V.1), my individual contributions (V.2), and the research articles themselves (V.3 – V.7).

II. Overview and Context of the Research Articles[2]

1 Challenges and Opportunities of BPM in the Digital Age

Digitalization brings socio-technological change and poses challenges and opportunities for organizations. This circumstance challenges existing business processes and BPM more generally (Gimpel et al. 2018). Academics and practitioners have agreed that BPM acts as a driver for process implementations and adaptions (Dumas et al. 2018; Harmon 2018; Legner et al. 2017). Against this background, digitalization is driving the reconceptualization of BPM in the digital age (Klun and Trkman 2018; Rosemann 2014; van der Aalst 2013). However, before reconceptualizing BPM, an in-depth understanding of the way digital transformation is reshaping BPM – in terms of both challenges and opportunities – is essential. Hence, this section presents an empirically validated collection of current challenges and opportunities before drawing new, enhanced, and as-is capability areas that are structured in a comprehensive framework (Section II.1 – research article #1). Next, an elaboration of an experiment into process compliance examines process deviance, revealing the potential of positive deviance as a catalyst for improvement. This work extends the general understanding and addresses an important challenge and opportunity highlighted by experts (Section II.2 – research articles #2 and #3). Moreover, this work investigates the need for advanced automation via the incorporation of mobile devices to provide support – in particular, decision support – in production processes (Section II.2 – research articles #4 and #5).

Research article #1 presents an updated capability framework for structuring new, enhanced, and relevant extant BPM capability areas for the digital age. This research article highlights 14 key challenges and opportunities for the upcoming 5 to 10 years, which are structured around six core elements (i.e., Strategic Alignment, Governance, Methods, Information Technology, People, and Culture). These results will guide academics and bring their BPM perspective into clearer focus. As for practical utility, industry experts can use the updated capability frameworks to structure further discussions of organizations' BPM capabilities.

The Delphi study inspired the methodological approach of reaching consensus on BPM capabilities in a group of experts (Dalkey and Helmer 1963; de Bruin and Rosemann 2007). The Delphi study design was twofold. Firstly, to establish a common understanding, academic and industry panelists listed and agreed on challenges and opportunities. Later, they shortlisted all items. Consensus was achieved by selecting those items that a majority of one panel identified as important. Secondly, in

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the iterative nature of Delphi studies (Paré et al. 2013; Schmidt 1997), the panelists named, validated, and allocated capability areas to core elements until consensus was reached.

The first contribution is the shortlist of challenges and opportunities for the upcoming 5 to 10 years, which addresses the core elements of the original BPM capability framework elaborated by de Bruin and Rosemann (2007). The framework suited the needs of the broad focus of BPM as it has been adapted by several organizations (van Looy et al. 2017). The core elements provide a comprehensive overview, particularly detailing the lifecycle and operational process support of BPM (Rosemann and vom Brocke 2015). Hence, the six core elements (Rosemann and vom Brocke 2015) seemed suitable for holistically structuring the challenges and opportunities and for use as a basis for the update in the next step.

Table 1 shows that more than 50% of the challenges and opportunities address future circumstances in the core elements of Methods or Information Technology. These eight challenges and opportunities also received the most votes from academic and industry experts, indicating their importance. In the original capability framework, the core elements Methods and Information Technology reflect the lifecycle phases of BPM and consistently contain the same capability areas, albeit from different perspectives (Rosemann and vom Brocke 2015). These results conclusively demonstrate that the related capability areas are necessary for the successful implementation of BPM as it makes up a third of the entire original framework. Moreover, challenges and opportunities that received the highest votes are in the core element of Methods and Information Technology. In order to empirically answer the central research question about the method-based design of artifacts, the two shortlisted items that are considered important in the core element of Methods are the analytical lens of this thesis. The shortlist of challenges and opportunities and the original BPM capability framework (de Bruin and Rosemann 2007) (Figure 2) served as input for the main contribution.

Strategic Alignment	**Governance**	**Methods**	**Information Technology**	**People**	**Culture**
Process Improvement Planning	Process Management Decision-Making	Process Design & Modeling	Process Design & Modeling	Process Skills & Expertise	Responsiveness to Process Change
Strategy & Process Capability Linkage	Process Roles and Responsibilities	Process Implementation & Execution	Process Implementation & Execution	Process Management Knowledge	Process Values & Beliefs
Enterprise Process Architecture	Process Metrics & Performance Linkage	Process Monitoring & Control	Process Monitoring & Control	Process Education	Process Attitudes & Behaviors
Process Measures	Process-Related Standards	Process Improvement & Innovation	Process Improvement & Innovation	Process Collaboration	Leadership Attention to Process
Process Customer & Stakeholders	Process Management Compliance	Process Program & Project Management	Process Program & Project Management	Process Management Leaders	Process Management Social Networks

Figure 2. de Bruin and Rosemann's (2007) BPM capability framework

Table 1. Challenges and opportunities of BPM in the next five to ten years

Challenge/Opportunity	T %	A %	I %
Strategic Alignment			
BPM should deliver purposeful, measurable results of strategic importance. (*)	53.6	40.0	69.2
BPM should take an integrated perspective on business goals, processes, systems, participants, and data.	71.4	60.0	84.6
Governance			
BPM should ensure end-to-end process control and compliance without unnecessarily constraining process participants. (**)	67.9	66.7	69.2
BPM should treat business processes as parts of intra- and inter-organizational process networks.	64.3	73.3	53.8
Methods			
BPM should enable dealing with unpredictable, inter-organizational, fragmented, and knowledge-intensive business processes.	64.3	73.3	53.8
BPM should be applicable in fast-changing and hyper-competitive organizational contexts.	60.7	53.3	69.2
BPM should leverage digital technologies for streamlining and innovating business processes. (**)	89.3	86.7	92.3
BPM should enable fast and intuitive process design, deployment, analysis, and improvement. (*)	67.9	80.0	53.8
BPM should enable customer-centric process design, analysis, and improvement. (*)	60.7	40.0	84.6
Information Technology			
BPM should explore new ways of automating unstructured tasks and complex decisions. (**)	78.6	80.0	76.9
BPM should leverage data for predictive and prescriptive purposes. (*)	60.7	73.3	46.2
BPM should explore the potential of unstructured and non-process-related data. (*)	75.0	100.0	46.2
People			
BPM should account for the effects of business processes on people's work lives.	64.3	60.0	69.2
Culture			
BPM should foster an opportunity-driven mind-set. (*)	46.4	26.7	69.2

T = Total votes A = Votes of academic experts I = Votes of industry experts

** Difference between the votes of academic and industry experts >25 %-points.*

*** Difference between the votes of academic and industry experts <5 %-points.*

Following the challenges and opportunities, the capability areas formed the focus of the second step in the Delphi study. Capability areas are repeatable patterns of action using assets (Wade and Hulland 2004) and technical and managerial skills (Amit and Schoemaker 1993). The aim of the capability areas is to establish future-oriented, effective, and efficient business processes, primarily to ensure corporate success (de Bruin and Rosemann 2007; Lehnert et al. 2016). Originally, the framework consisted of 30 equally-distributed capability areas (de Bruin and Rosemann 2007).

The main contribution is the updated capability framework for BPM in the digital age. The framework is shown in Figure 3. The first contribution yielded a capability framework consisting of five core elements (i.e., Strategic Alignment, Governance, Methods / Information Technology, People, and Culture). Each core element is comprised of between five and ten capability areas. Comparing the two frameworks shows that 27 of 30 capabilities are either new or enhanced. The core elements most affected are Methods / Information Technology, People, and Culture. In particular, the core element Methods / Information Technology has been reconceptualized by merging the two formerly-separate core elements. The focus has shifted from lifecycle phases to a more comprehensive technology- and method-based management. In general, the empirical insights validate the immense impact of digitalization on BPM as the changes from the experts indicate that all core elements are affected. That shows how digitalization holistically influences organizations and their underlying business processes. The major changes in the merged core element strengthen the assumption to analyze the related challenges, opportunities, and capability areas in detail in the next step.

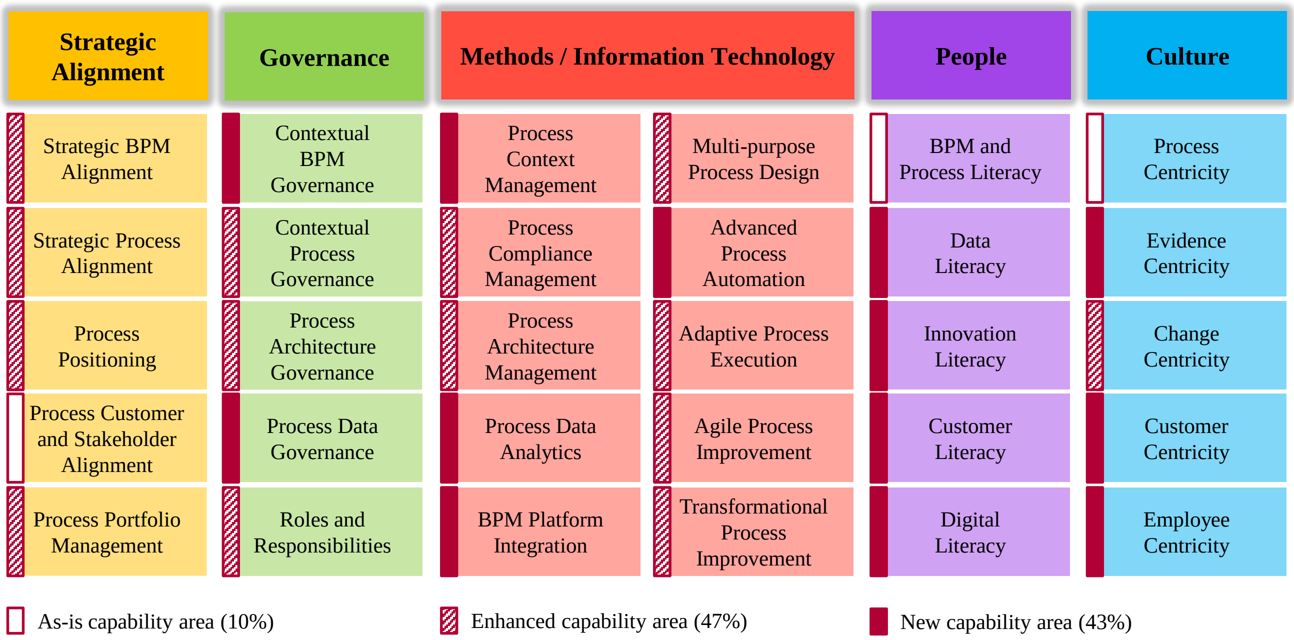


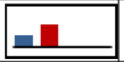
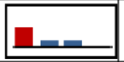
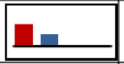
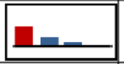
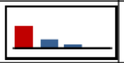
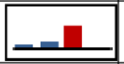
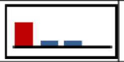
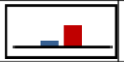
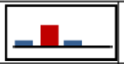
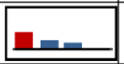
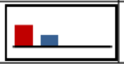
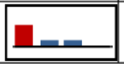
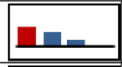
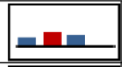
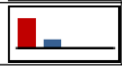
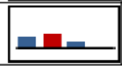
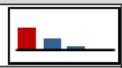
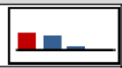
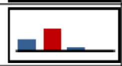
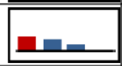
Figure 3. Updated BPM capability framework (including comparison)

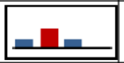
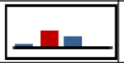
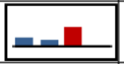
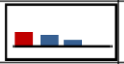
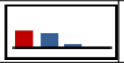
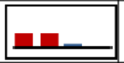
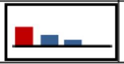
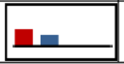
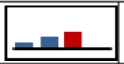
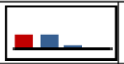
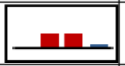
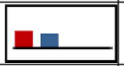
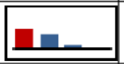
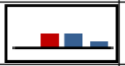
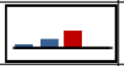
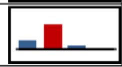
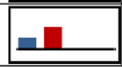
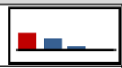
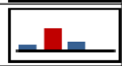
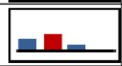
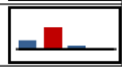
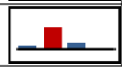
2 Process Compliance Management: Understanding & Influencing Business Process Deviance

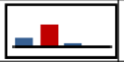
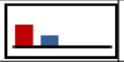
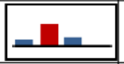
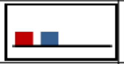
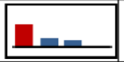
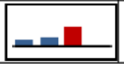
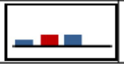
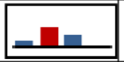
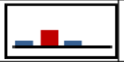
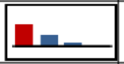
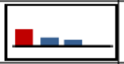
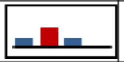
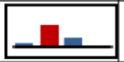
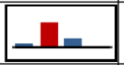
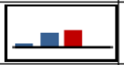
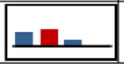
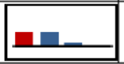
Corporate success as a central goal of BPM is operatively located in the merged core element Methods / Information Technology, defined by de Bruin and Rosemann (2007) as "*the approaches and techniques that support and enable consistent process actions and outcomes*" and "*the software, hardware, and information management systems that enable and support process activities*" (de Bruin and Rosemann 2007, p. 649). This is also supported by the related challenge and opportunity, Methods, which calls for a "*fast and intuitive process design, deployment, analysis, and improvement*" (Kerpedzhiev et al. 2020, p. 7). The enhanced capability area *"Process Compliance Management"* extends the former capability areas in terms of the BPM lifecycle phases Process Monitoring and Improvement. *"Process Compliance Management"* is defined as the "*specification of requirements regarding regulations, goals, performance, risks, security, privacy as well as detection, monitoring, and handling of detrimental and constructive process (non-)compliance, leveraging predictive techniques whenever reasonable*" (Kerpedzhiev et al. 2020, p. 9). The second part of this description emphasizes process (non-)compliance, which is the conformance of a process with initial definitions (Alter 2015b). A non-compliant process can be seen as deviating from its process design (Alter 2015b; Andrade et al. 2016; Chakraborty 2013; Delias 2017; Dumas and Maggi 2015). Such process deviance impacts the process performance, either positively or negatively, and will be either consistently detrimental or constructive from a compliance point of view (Alter 2014; Spreitzer and Sonenshein 2004). Positive intended deviations are intuitive sources for process improvements and inspiration for transforming the positive deviations to new process definitions (Andrade et al. 2016; Mertens et al. 2016). This addresses the challenge and opportunity of fast and intuitive process improvement, as process participants have already adopted the deviant process definition. Accordingly, the updates required to improve a process are quick to implement.

Against this background, research article #2 provides a comprehensive understanding of process deviance while presenting a shortlist of 33 reasons for process deviations, compiled from a process managers' perspective. This shortlist is intended to provide a holistic and context-independent overview of the reasons for process deviations. This overview offers guidance to process managers, fostering a deeper understanding of compliance violations. Table 2 presents 33 reasons clustered into nine categories (i.e., the process itself, process documentation, process change, customer, knowledge and skills of process participants, attitudes and behavior of process participants, resources, governance and strategic alignment, and IT in use) and their importance (A: extremely important; B: very important; C: important; D: unimportant) for routine and nonroutine processes.

Table 2. Shortlisted reasons for process deviance

The Process Itself	**R**	**NR**	**R Median**	**R Modus**	**NR Median**	**NR Modus**	**p-value**
The process deals inappropriately with different contexts.**			B	B	A	A	0.00020
The process is unable to cope with unexpected events.			A	A	A	A	0.69800
The process includes inappropriate tasks.***			A	A	C	C	0.00000
The process includes an inappropriate control flow.***			A	A	C	C	0.00000
Process Documentation							
The process documentation is hard to access and/or not clearly communicated.*			B	B	B	B	0.00187
The process documentation was created without consulting relevant process participants and stakeholders.*			A	A	A	A	0.00118
The process documentation is missing or incomplete.*			A	A	A	A	0.00128
Process Change							
The process is infrequently checked for up-to-dateness.			B	A	B	B	0.13886
The process was designed without consulting relevant process participants and stakeholders.**			A	A	B	B	0.00009
Customer							
Customers impose unexpected requirements on the process.			A	A	B	A	0.86187
Customers change their requirements while the process is being executed.			B	B	B	A	0.09299

Knowledge and Skills of Process Participants	R	NR	R Median	R Modus	NR Median	NR Modus	p-value
Process participants do not have relevant knowledge and/or skills.**			A	A	A	A	0.00067
Process participants do not have sufficient routine in executing the process.*			B	B	B	B	0.00154
Process participants do not know how their work contributes to the overall process outcome.*			C	C	B	A	0.00181
Process participants are unaware of escalation strategies for dealing with unexpected events.			B	A	B	A, B	0.94622
Process participants are unaware of their roles and responsibilities.			B	A	A	A	0.14742
Attitudes and Behavior of Process Participants							
Process participants do not identify themselves with the objectives of the process.***			C	C	B	A	0.00000
Process participants are unmotivated. ***			C	B, C	B	A	0.00000
Process participants tend to change the process by themselves.***			B	A	A	A	0.00000
Process participants are often interrupted at work.			C	B	C	C	0.19284
Process participants do not communicate with one another and/or the process owner if needed.			B	B	B	B	0.28489
Resources (i.e., material, equipment, employees)							
Resources tend to be temporarily or systematically unavailable.***			A	A	B	A	0.00000
The process competes with other processes for scarce resources.			B	B	B	B	0.61405
Resources do not scale with varying workload.			B	B	B	B	0.29867

Governance and Strategic Alignment	R	NR	R Median	R Modus	NR Median	NR Modus	p-value
The process has no defined process owner.***			B	B	A	A	0.00000
The process owner is equipped with insufficient authority.**			B	B	B	A	0.00062
Roles and responsibilities within the process are missing or specified ambiguously.***			A	A	B	A	0.00000
Stakeholders have unrealistic expectations regarding process performance.			C	C	B	B	0.39642
IT in Use							
Required data is scattered over multiple sources.			B	B	B	B	0.69817
Relevant IT systems do not provide the required functionality.			A	A	A	A	0.76584
Relevant IT systems have unnecessarily complex user interfaces.			B	B	B	B	0,19873
The process requires many and/or non-integrated IT systems to be used.			B	B	B	C	0.08129
Process participants do not have access to relevant IT systems and/or data.			B	B	B	A	0.97908

*R: routine; NR: nonroutine; A: extremely important; B: very important; C: important; D: unimportant; Significance codes: p<0.0001:***, p<0.001: **, p<0.01:*, p<0.05: no cod*

An exploratory Delphi study was carried out to collect and rate the 33 reasons (Keeney et al. 2006; Okoli and Pawlowski 2004). The study was structured in three phases, according to Schmidt et al.'s (2001) approach. In an initial brainstorming phase, the study experts were asked to list reasons for process deviance. They were then asked to narrow down these reasons to create a more manageable list of 33. The aim in the last phase – rating – was for experts to reach a consensus about the relative importance of routine and nonroutine processes per reason. Finally, an analysis of the descriptive measures Median and Modus and the results of a statistical test showing differences between the relative importance of different reasons highlighted the need for further, in-depth deviance research in various contexts. The results are useful for academics, examining process deviance as a multi-causal and somehow intangible concept, and for practitioners, seeking to quickly analyze and assess the extent to which processes are susceptible to deviations.

Research article #2, firstly, defines deviance based on the extant literature, examining related concepts such as exceptions, workarounds, and non-compliant processes (Alter 2015a, 2015b; Rinderle and Reichert 2006). Deviance has its origin in psychology and examines deviant human behavior (Robinson and Bennett 1995), which manifests in either intentional or unintentional actions against norms and standards that might be harmful (Spreitzer and Sonenshein 2004). Based on this recognition, and extended with findings from the BPM literature, a process-oriented definition covering the intersection of scope, frequency, and intention is provided: "*Process deviance indicates that a business process shows different behavior than intended. It may occur in individual tasks, sub-processes, or the entire process (scope). Process deviance may occur in one process instance, various or all process instances (frequency). Finally, it may also occur intentionally or unintentionally (intention)*" (König et al. 2019, p. 430). The concept of process non-compliance also recognizes these characteristics, although compliance checking spots violations of predefined specifications (Alter 2015b).

In contrast, process deviance is broader and can be evaluated by assessing softer factors such as human attitudes and behavior. To provide a holistic perspective, the reasons for process deviance are rated in terms of their importance in routine and nonroutine processes. The intention is to analyze and compare the reasons for deviance in multiple contexts. Routine processes are well-defined and regularly executed. In contrast, nonroutine processes deal with semi- or unstructured problems and involve a certain flexibility (Lillrank 2003). However, nonroutine processes cannot be specified prior to execution, as is usually the case with imperative process models (Lillrank 2003). These contrary process types cover a vast number of processes and comprehensively represent the reality faced by process managers when managing process deviations. Unsurprisingly, more than 50% (17 out of 33) of the identified reasons for process deviance show different levels of importance in relation to routine and nonroutine processes. Hence, deviance management does not follow a one-size-fits-all approach and requires context-specific consideration.

In response to this understanding of process deviance, research article #3 presents insights from an experimental study on fostering positive process deviations, aiming to identify starting points for process improvement initiatives. As stated, positive process deviations or constructive compliance violations provide a useful starting point as process participants already have changed the process (Mertens et al. 2016). Furthermore, the challenge and opportunity of *fast and intuitive process improvement* – vital in a digital VUCA world – must be deployed quickly and easily (Bennett and Lemoine 2014). The VUCA characteristics require straight-forward methods that can be rapidly implemented, requiring significantly less effort than resource-intensive process improvement initiatives (Satyal et al. 2019). Hence, the contribution of research article #3 is the proposal of a new approach that uses digital nudging to open up process improvement opportunities and is highly relevant for academics and practitioners who seek to quickly realize improvement potentials.

The study followed an online "black box testing" experiment approach based on two business processes. Overall, the study was positioned as a non-hypothetical, descriptive, and causation-demonstrating experiment (Andersson 2012). In the experiments, 473 participants – each with a master's degree or relevant work experience – contributed and selected decision options and described their thoughts. These descriptions were independently coded to assess the participant's intentions to deviate. The results were then statistically analyzed to assess the probability of independence of nudges against the results of a control group (i.e., without nudging implementation). Moreover, a sub-group comprising participants with prior experience in customer service was separately analyzed to validate the results. This approach justified the results and decreased the bias of inexperienced and newly trained participants.

Digital nudging has its roots in psychology and is defined by the general construct of nudging and the underlying theory of dual-processing (Evans 2008). The overall aim of nudging is to improve peoples' decisions by altering their choice architecture (Thaler and Sunstein 2008). The decision space is called the choice architecture and is designed by a choice architect who determines the overall setting and structures and proposes decisions available to participants, using nudges. The main aspects of alternations are so-called nudges (Thaler and Sunstein 2008). Nudging transferred into digital choice architectures – i.e., online environments or user interfaces – and facilitated by information technology is referred to as digital nudging (Mirsch et al. 2017; Weinmann et al. 2016). Digital nudges are characterized by faster and cheaper implementation compared to their physical pendants (Mirsch et al. 2017). Table 3 depicts the most commonly used nudges, a brief description of each one, and references to the numerous nudges available that have proven their effectiveness.

Table 3. Nudges extracted from the literature

Nudge	Description	Studies showing effectiveness
Incentive	Showing consequences of the decisions made (Hansen and Jespersen 2013)	Houde et al. (2013); Noar et al. (2016)
Salience	Designing important information more prominent (Mann and Ward 2007)	Chetty et al. (2009); Pahuja and Tan (2017)
Precommitment	Getting the precommitment of people to engage in a certain behavior (Dolan et al. 2012)	Ashraf et al. (2006)
Default Setting	Using default settings to remain with the status quo (Mirsch et al. 2017)	Halpern et al. (2007); Goldstein et al. (2008)
Additional Information	Offering additional information to improve decisions (Schneider et al. 2017)	Khern-am-nuai et al. (2017); Schneider et al. (2017)
Social Norms	Providing information about rules and standards of a group (Mirsch et al. 2017)	Croson and Shang (2008); Bond et al. (2012)
Scarcity	Pretending a choice option to be scarce (Mirsch et al. 2017)	Schneider et al. (2018)

Transferring the potential of digital nudging into BPM, the idea behind research article #3 was to alter the choice architecture of process workers and foster better decisions in terms of positive intentions towards deviations from established processes (Andrade et al. 2016). Andrade et al. (2016) identified two business processes prone to positive deviations that served as the foundation for the choice architecture. According to Andrade et al. (2016), the business processes "Account Deletion Process" (ADP) and "Technical Request Process" (TRP) within a major German IT organization showed improvement possibilities. Both processes have already shown constructive non-compliant behavior and are easily understandable for non-domain experts. The ADP consists of process activities to react to a customer's request to delete their user account while holding a positive balance. The TRP is actioned when a customer has requested technical help. The organization aims to support problem-solving by presenting multiple options or carrying out internal inquiries for help to respond to the request.

For each process, five nudges – *incentive, precommitment, salience, default setting, additional information* – were implemented. The nudges *incentive* and *salience* revealed relevant information which the process workers had to read prior to execution. *Precommitment* asked process workers to commit to providing excellent customer service. The nudge *default setting* preselected options according to the definition of the process model on the user interface. In a process environment where the *additional information* nudge had been implemented, process workers were shown the underlying process model before the process execution started. Figure 4 exemplarily shows the representation of the nudge *salience* in ADP. The incorporation of the nudges into ADP and TRP showed promising results, demonstrating that nudging leads to positive deviations in both processes. The nudges *incentive* and *salience*, however, outperformed the other nudges, as shown in Table 4.

Figure 4. The actual presentation of the nudge *salience* (ADP)

Table 4. Relative positive deviance detected per process and across the entire sample (total)

	Control Group	Incentive	Pre-commitment	Salience	Default Setting	Additional Information
ADP	44%	80%	53%	71%	38%	53%
TRP	43%	74%	51%	60%	30%	47%
Total	43%	77%	52%	66%	34%	49%

The results showed that it is possible to easily and quickly implement digital nudges in automated process execution environments and that positive effects can be realized. Therefore, research article #3 advances existing research (Fellmann et al. 2018) and stimulates research on process improvements via constructive compliance, which is demonstrated to be an agile approach for realizing process improvements. These findings also benefit practitioners, who can use the results to profit from a light-weight approach to agile business process improvement initiatives.

To conclude Section II.2, the investigation and practice-inspired experiment of positive deviance advances the capability area *"Process Compliance Management"*. The results of research article #2 advance the general understanding of deviance. Process deviance materializes, either negative or positive. Particularly, positively intended deviations offer vast potential for process improvement initiatives if purposefully noticed and managed. Furthermore, in research article #3, the meaningful nudge of positive deviance opens an agile approach to identifying sources for improvement initiatives. The lightweight initiatives compete with established mechanisms to drive rapid improvements and innovations. The investigation of digital nudging innovatively advances improvement methods and validates the potential of becoming an agile approach for seeking improvement potentials of processes.

3 Advanced Process Automation: Leveraging Mobile Devices in Production Processes

In keeping with findings from Section II.2, a newly emerged capability area, namely "A*dvanced Process Automation,*" is the focus of Section II.3. This new capability area features in the merged core element Methods / Information Technology. The challenge and opportunity rated as most important in terms of Methods is, thereby, addressed. Over 89% of the experts involved in the Delphi study on BPM capabilities in the digital age argue that "*BPM should leverage digital technologies for streamlining and innovating business processes*" (Kerpedzhiev et al. 2020, p. 7). Therefore, this section focuses on digital technologies – in particular, mobile devices – and their automation opportunities for BPM. The capability area "*Advanced Process Automation*" consequently subsumes actions required for leveraging digital technologies as follows: "s*ystematic exploitation of automation technologies (e.g., robotic process automation, cognitive automation, social robotics, and smart devices) to assist human process participants in unstructured tasks and complex decisions or to fully automate such tasks and decisions"* (Kerpedzhiev et al. 2020, p. 10). Thus, research articles #4 and #5 describe how manufacturers can utilize mobile devices to yield better process performance. Research article #4 provides a generalized approach for incorporating mobile devices to improve existing production processes. It also addresses the assistance part of the capability area introduced in this section. In contrast, research article #5 presents an innovative way to use smartphones to mitigate maintenance costs and support complex decisions, combining smartphones and artificial intelligence to propose a simple predictive maintenance toolbox.

Research article #4 contributes a software artifact, consisting of a middleware and client application, as an instantiation and source for general design principles (DP) that assist the incorporation of mobile devices in the manufacturing area. The program Industry 4.0, initiated in Germany, encourages and supports small and medium-sized manufacturers (SMMs) to keep pace with incumbents (Alcácer and Cruz-Machado 2019; Kagermann et al. 2013; Lasi et al. 2014). The basic incorporation of mobile devices into production processes connects production machines, information systems, and production employees and facilitates faster information flows and process execution (Geißler et al. 2019; Stentoft et al. 2020). The results are suitable for SMMs as they guide the incorporation of mobile devices and enable SMMs to use two in-depth, tested tangible software artifacts. Academics profit from empirical insights intended for real-world application and from the proposal and extension of general DPs (Hermann et al. 2016).

The artifacts, DPs, and empirical insights from research article #4 are derived following an ADR approach (Mullarkey and Hevner 2019; Sein et al. 2011) supplemented by a consortium research approach (Österle and Otto 2010). The research was inspired by the practical involvement of four SMM and two software companies, who closely collaborated with the researchers in four interconnected project cycles (i.e., diagnosis, design, implementation, and evolution) (Mullarkey and Hevner 2019). The evaluation involved 60 production employees from diverse backgrounds who assessed the applicability and ease-of-use. The evaluation structure was inspired by Davis' (1985) technology acceptance model. Ultimately, a majority of the production employees expressed their willingness to potentially use the artifacts in the future thanks to the materialization of benefits such as process efficiency, improved communication, and higher data quality.

During the research project, it was possible to generate multiple intermediate results in the four-cycle procedure (Mullarkey and Hevner 2019). Table 5 presents the intermediate results of the collaboration. The consortium analyzed the status quo and highlighted room for improvement, resulting in eight use-cases and the selection of incorporable mobile devices. Moreover, during the design cycle, a generally applicable software architecture and corresponding requirements for mobile device incorporations in SMMs were derived. In the last cycles, the focus was on implementing, testing, and continuously reshaping the main artifacts (i.e., middleware and client-application).

Table 5. Overview Artifacts

Cycle	Stage / Activity	Intermediate results
Diagnosis	P: Structuring the problem domain A: Use-case collection E: All hands workshops R: Prioritization during a workshop L: Mobile device selection	• Use-case collection • Mobile device selection
Design	P: Design of the artifacts A: Middleware architecture E: Onsite workshops at SMMs R: Revision of architecture L: Validation with SMMs	• Software architecture • Requirements
Implementation	P: Instantiation of architecture A: Middleware & client application E: Installations on side R: Software updates L: Integration of machine operators	• Middleware prototype • Client application prototype
Evolution	P: Evaluation and test artifacts A: Middleware & client application E: Interviews R: Software updates L: Comprehensive evaluation	• Middleware prototype • Client application prototype • In-depth evaluation

(P) Problem formulation / Planning | (A) Artifact creation | (E) Evaluation | (R) Reflection | (L) Learning

The middleware, as the main artifact, ensures the connection of – and flow of information between – different entities, i.e., production machines, information systems, and mobile devices (Figure 5 on the right). The key aim stated by the SMMs was the realization of an easy-to-understand and maintainable solution. Hence, the key component of the middleware is the rule engine, consisting of two subsystems. The rule engine can be configured using established program languages such as extensible markup language (XML). Rules define easily extendable information flows between the external entities. Furthermore, rules apply only straightforward configurations, i.e., rules analyze the input according to basic mathematical operators, i.e., =, >, and <. More complex computations are part of external information systems, which encourage a highly maintainable and easy-to-understand approach. Additional subsystems – i.e., programmable logic controller (PLC) integration – and the mobile device gateway receive information either from production machines or mobile devices and route this information to the rule engine internally.

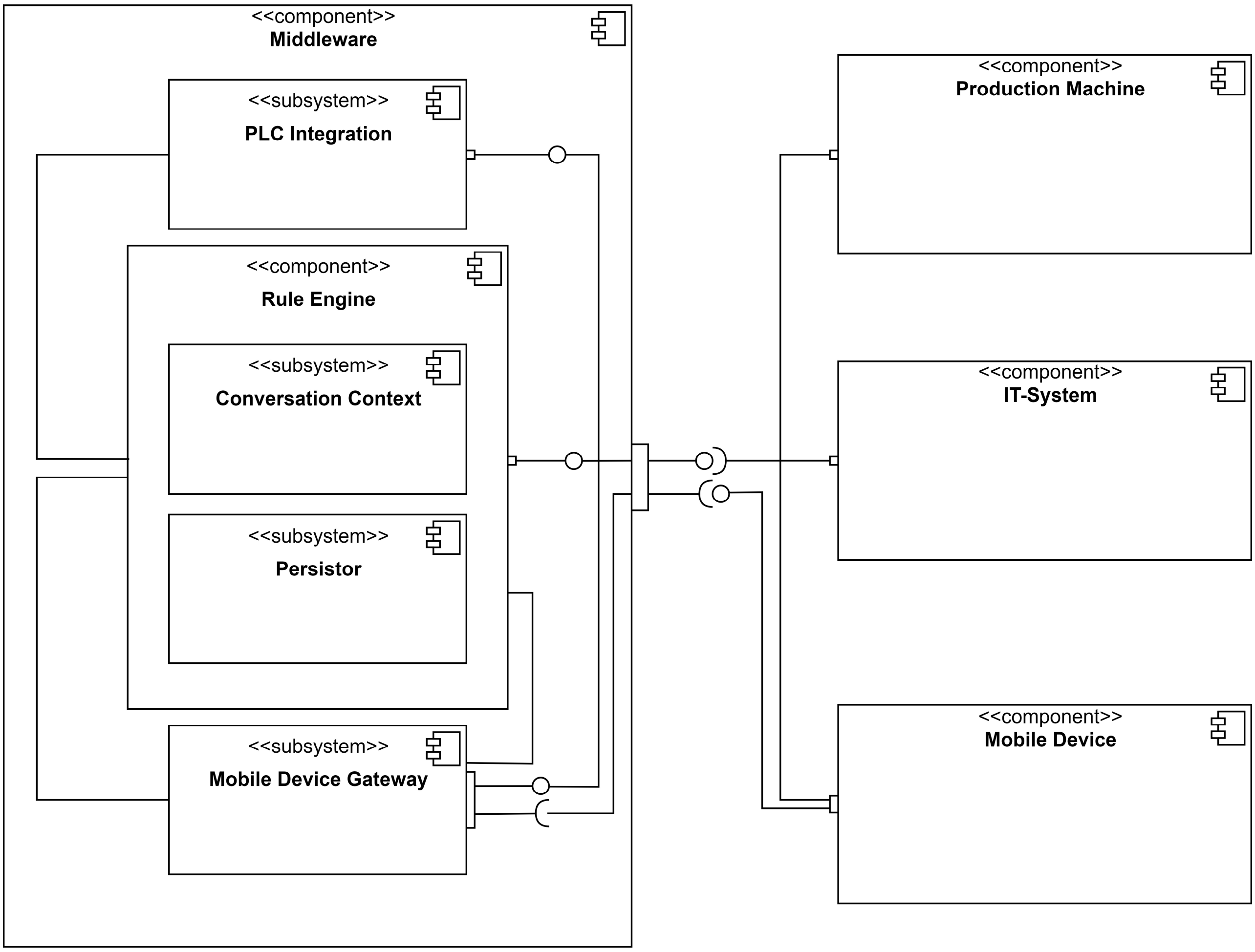


Figure 5. The architecture of the middleware

Following the design and real-world evaluation, the insights steered toward assumptions about future implications and, finally, to general DPs to assist academics and practitioners in future initiatives (Zschech et al. 2020). Table 6 presents the final DPs. The first considers the machine operators' perspective on their tasks. Whenever possible, machine operators should individually choose mobile devices that fit their personal needs and tasks. The following three DPs focus on the design of the middleware, which is easy to configure, maintainable, and avoids unnecessary complexity by excluding specific business logic. Summing up, research article #4 demonstrates the feasibility of mobile devices as a means to improve and automate processes. Furthermore, SMMs agreed on the challenge of leveraging the adoption of new technologies. At the same time, they saw enormous potential to facilitate manifold opportunities and innovations.

Table 6. Overview of Design Principles

Title	Description
DP1 – Consider multiple device types	*Key Idea:* Provide multiple devices types that machine operators can choose from *Rationale:* Support different task types *Potential Realization:* Implement applications to run on various mobile devices
DP2 – Ensure platform independency	*Key Idea:* Provide open and standard interfaces *Rationale:* Ability to handle heterogeneous systems and production entities at SMMs *Potential Realization:* Offer easily adaptable interfaces for various systems
DP3 – Support easy configuration	*Key Idea:* Provide a familiar and comfortable way to configure rules and workflows *Rationale:* Empower SMMs' limited human resources to easily adjust software artifacts *Potential Realization:* Use common standards such as XML
DP4 – Separate context-specific business logic	*Key Idea:* Use separate components to compute business logic *Rationale:* Ensure a straightforward and maintainable configuration *Potential Realization:* Ensure maintenance and modularity of the core components
DP5 – Use intuitive user interfaces	*Key Idea:* Increase machine operators' willingness to participate *Rationale:* An intuitive GUI lowers the barriers to entry and resistance to change *Potential Realization:* Design user interfaces in an intuitive way

In order to enhance the basic potential of mobile devices to automate and assist production processes, research article #5 goes one step further and presents a reference architecture and two reference processes for smartphone-enabled predictive maintenance. Yet, research article #5 not only supports process participants and circulates of information. It extends the insights of research article #4 by incorporating artificial intelligence as additional digital technology to provide complex decision support. The project idea was developed by practitioners who expressed the need to understand predictive maintenance and its functionalities better. Moreover, the approach should be able to operate with existing, partially-outdated production machines, and should be scalable. Research article #5 is equally relevant for academia and industry as it shows what a theoretically evaluated approach on the intersection of predictive maintenance and smartphones as data collectors can look like and how it might be used in the production area. Initial evaluation attempts – i.e., prototype instantiations of the artifacts and real-world tests – further demonstrated the applicability and usefulness.

Like research article #4, research article #5 followed the four ADR research cycles, diagnosis, design, implementation, and evolution (Mullarkey and Hevner 2019). Yet, in contrast to research article #4, the aim of research article #5 was to extend the currently available knowledge and add design and diagnosis insights in terms of descriptive as well as prescriptive knowledge. Throughout the project, five manufacturers and one software company provided their support, opinions, and insights. Furthermore, one manufacture adopted the prototypes in its production and provided first insights from real-world applications.

In contrast to preventive and reactive maintenance (Stenström et al. 2016; Swanson 2001), predictive maintenance offers automated recommendations for production machine maintenance demands before actual or unforeseen breakdowns, tool breakages, etc., occur (Mobley 2002; Schleichert 2017; Swanson 2001). Providing automated decision support, predictive maintenance uses, and specifically requires, data collections and algorithms. Analysis algorithms use classifiers (Mobley 2002) for the associated predictions to reduce costs, and increase machine uptimes and lifetimes, in general (Goodfellow et al. 2017; Gu et al. 2017; Schleichert 2017). Modern production machines are already equipped with internal sensors and interfaces for predictive analysis purposes (Roy et al. 2016). However, older operational production machines in good condition require external technologies to collect data (Civerchia et al. 2017; Groba et al. 2007; Mobley 2002). Smartphones as handheld devices equipped with a vast array of sensors offer a scalable option for manufactures to gather machine data, make predictions, and present these predictions directly to users via the smartphone display (Chatterjee et al. 2018; Gimpel et al. 2019; Legner et al. 2016).

Hence, a smartphone-enabled predictive maintenance solution was developed, consisting of a reference architecture and processes, prototype instantiations, and test installations. Figure 6 shows the initial result of the diagnosis cycle in terms of a smart service model as introduced by Huber et al. (2019). The smart service model is a domain-specific modeling language that provides an overview of various components, functions, and information flows of cyber-physical systems – such as industry 4.0 initiatives – to yield a better understanding of the application domain (Huber et al. 2019).

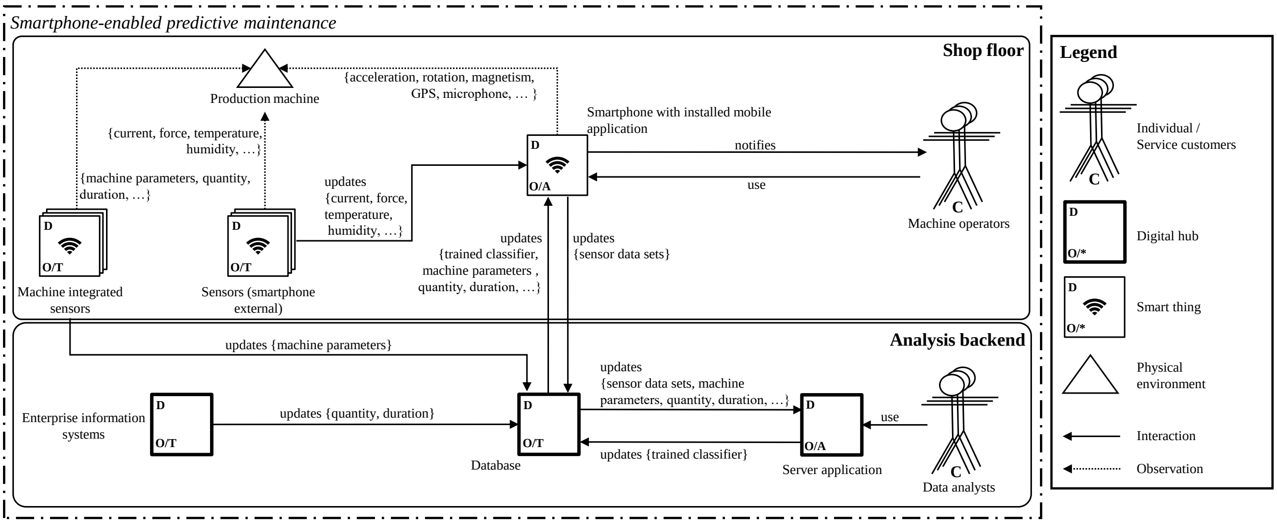


Figure 6. Smartphone-enabled predictive maintenance as a smart service model

The smartphone-enabled predictive maintenance smart service model is comprised of two service systems: the shop floor and the analysis backend. The shop floor consists of components that are required for the monitoring of production machines. Machine operators use a smartphone with an installed mobile application to collect data from production machines or to receive notification of critical machine conditions and required maintenance tasks. The mobile application itself stores and distributes collected data to the analysis backend and receives trained classifiers. A data analyst provides support by observing the artificial intelligence (i.e., predictive maintenance algorithms) via a server application in the analysis backend. The core of the analysis backend is a database that receives data inputs from the shop floor (i.e., mobile application or machine-integrated sensors), enterprise information systems, and the server application. In the server application, the predictive maintenance, training, and actual creation of classifiers take place. Afterward, the classifiers are sent to the mobile application to compute maintenance demand using real-time data.

Going one step further, a software architecture provides meaningful insights into the functionality of the solution. Figure 7 depicts all of the crucial components and subsystems of the solution and is divided into three layers (i.e., data, application, and presentation layers). The data layer consists of two components: a method database and a database management system. The method database ensures a diverse number of potentially usable predictive maintenance algorithms for extracting classifiers are available to the server application as data inputs. As with the smart service model, the core is a database located and managed in the database management system component. This component aims to effectively and efficiently store a large number of data inputs. The application layer consists of the two applications (i.e., the server and mobile applications) and structures those subsystems necessary to either process data or create content for presentation purposes. The server application mainly comprises subsystems to compute and execute the machine-learning capabilities using the method database. It follows an established machine learning cycle that structures the tasks of data preparation, classifier modeling, classifier training, and classifier export (Goodfellow et al. 2017). The mobile application uses three subsystems to either collect data via smartphone sensors or use classifiers to monitor the conditions of production machines.

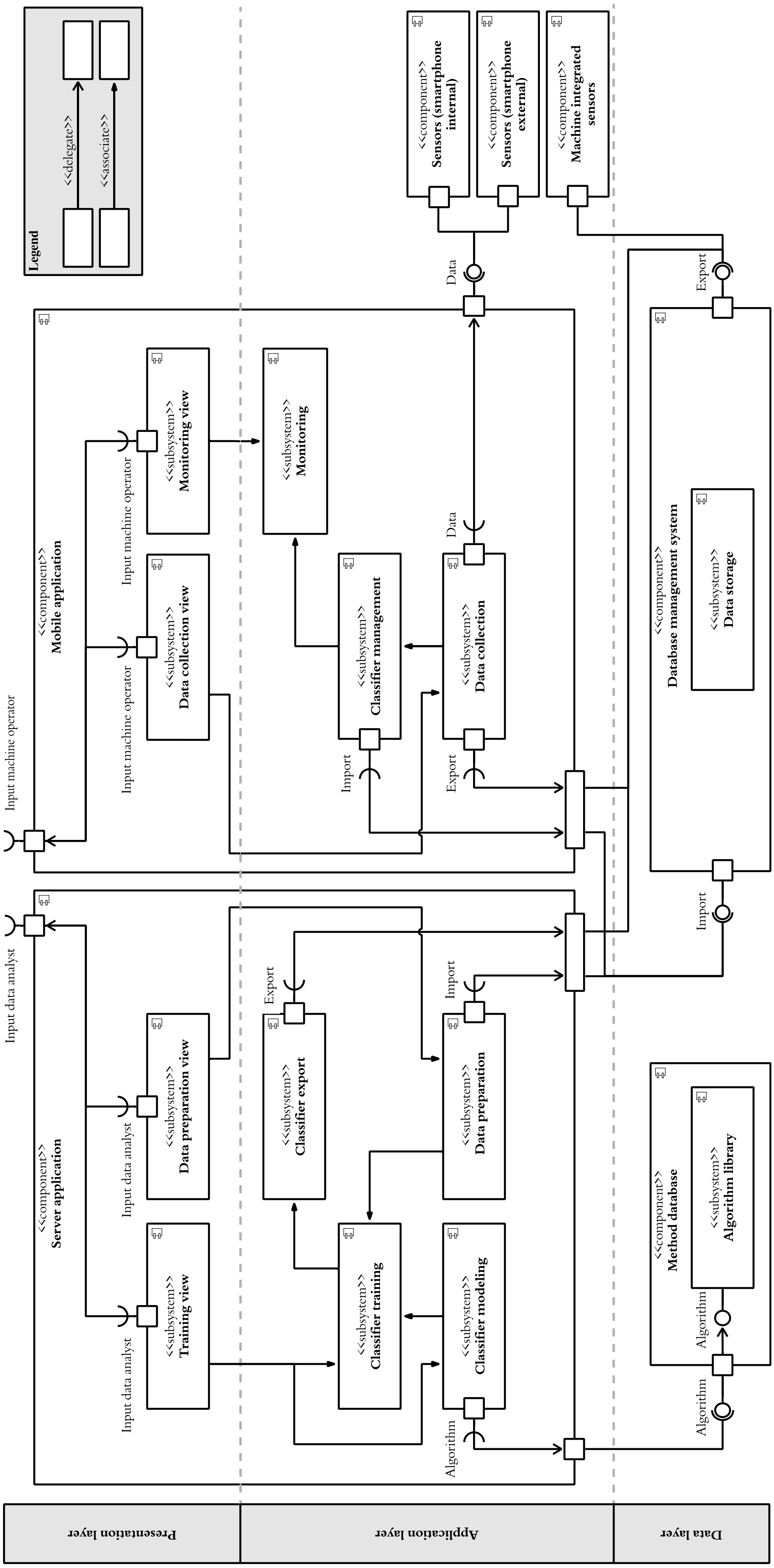


Figure 7. Software architecture for smartphone-enabled predictive maintenance

The presentation layer provides views for the data analyst and machine operator to make sure they can sufficiently work with the applications. The training view enables the management of the data and the creation of valuable classifiers. Before the classifier development, the data preparation view enables the data analyst to alter the data inputs to suit the prerequisites specified in the algorithm definition. The mobile application is split into data collection and monitoring views according to the machine operators' main tasks in the predictive maintenance processes. The graphical user interface skillfully guides the machine operator to data gatherings for multiple production machines in the data collection view. In contrast, the monitoring view presents the production machine conditions and notifies operators when (predictive) maintenance tasks are required.

According to the planning and design, one aim of research article #5 was to implement prototype instantiations and evaluate these in the company of industry experts. The industry experts examined the utility and feasibility of the artifacts and gave meaningful consideration to relevant contextual conditions, particularly in cases of older production machinery and SMMs.

To conclude Section II.3, the practice-inspired execution of two ADR projects shows the legitimacy and importance of the capability area *"Advanced Process Automation"* for adopting new technologies. The results advance the automation of production processes and open new opportunities – including efficient process communication and decision support – by implementing innovative solutions (e.g., predictive maintenance, machine learning, and artificial intelligence). What is more, the artifacts and the underlying new data sources also provide the potential for new services and products. Research article #4 reveals the key challenges and opportunities involved in the adoption of mobile devices for production process improvements, and contributes design knowledge and empirical insights. In a further step, research article #5 analyses new opportunities for manufacturers to advance the basic insights provided in research article #4. The research articles collectively provide descriptive and prescriptive knowledge for the introduction of automated decision support in SMMs and validate the explorative and primarily descriptive results of research article #1.

III. Summary and Future Research[3]

1 Summary

Digitalization has a tremendous effect on individuals, organizations, and social systems; specifically, on the underlying processes. If organizations are to survive under these changing conditions, it is more important than ever that they understand and manage the effects of the digital age. The number of new digital technologies – including artificial intelligence, robotics, automation, social collaboration, and new hardware types, such as smartphones or the IoT – increases organizations' lack of ability when it comes to adapting business processes and accessing clarification and guidance.

This thesis takes a structured empirical as well as a design-orientated approach to BPM in the digital age, using two specific capability areas (i.e., "*Process Compliance Management"* and *"Advanced Process Automation"*) as an analytical lens. This doctoral thesis is cumulative and contributes five research articles to the understanding, design, and implementation of digital technologies and methods at the intersection of BPM in the digital age, process compliance, and advanced automation to answer the central research question, which relates to the impact of digitization on BPM. The first research article shows evidence that digitalization generally imposes challenges and opportunities. These lead to changing circumstances, contexts, and emerging technologies. The changes encourage people to increase data, innovation, and digital literacy. Research articles #2 and #3 answer the second sub-research question, which is related to understanding compliance violations as a source for process improvements. Positive deviations initiated by digital technologies (i.e., digital nudging) pave the way towards agile and rapid process improvement initiatives. The last sub-research question about automation via mobile technologies profits from the design knowledge derived by research articles #4 and #5. Established and comparable cheap technologies automate the communication of organizations and eventually reduce waste to allow organizations to concentrate on their core competencies.

Research article #1 is based on an international Delphi study involving 29 academic and industry experts. The article presents 14 challenges and opportunities before, in Section II.1, providing an updated BPM capability framework for the digital age. The challenges and opportunities served as input for the main contribution (i.e., the capability framework) and yielded 30 equally distributed capability areas along the following five core elements: Strategic Alignment, Governance, Methods / Information Technology, People, and Culture. Three capability areas from the original framework

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

by de Bruin and Rosemann (2007) remained unchanged. The other 14 original capability areas were enhanced, and 13 new capability areas were added. This initial article serves as the foundation of the thesis.

Research article #2 addresses a challenge and opportunity linked to the core element, Methods, which calls for the rapid analysis, deployment, implementation, and improvement of processes. This second article presents explorative results suggesting the reasons behind process deviations. A prioritized list of 33 reasons for process deviance, rated accordingly for routine and nonroutine processes, advances the understanding of process deviance and compliance from a management perspective. The list could be used as a source for fast process analysis. Process managers can use the reasons as the first version of a checklist to assess their business processes' vulnerability to deviations. When vulnerability to positive deviations is observed, the results may indicate sources of process improvement initiatives. Going one step further, research article #3 builds on the previous insights and presents an experiment combining positive process deviance and digital nudging. This experiment investigated the possibility of changing process workers' behavior towards positive process deviations. The setup showed the ability to nudge people toward positive deviations in two exemplary business processes with a proneness for positive deviance. Two easy-to-implement digital nudges made significant positive changes to the behavior of process workers, confirming the opportunity for rapid and agile process implementation.

Research article #4 addresses the challenge and opportunity of leveraging digital technologies (i.e., mobile devices) to automate business processes. Accordingly, two prototypical instantiations were developed, along with five DPs for future investigations. Incorporating mobile devices such as smartphones and tablets via a middleware and client application improved and automated production processes. During the evaluation, 60 machine operators confirmed that the artifacts were applicable, easy to use, and capable of yielding production efficiencies. Research article #5 reveals the ability of smartphones to provide decision support using machine learning for predictive maintenance. In collaboration with five SMMs and one software company, it was possible to develop a reference architecture as well as processes for implementation and use. A preliminary evaluation confirmed that the architecture and processes were effective in providing decision support.

In sum, this thesis advances the overall knowledge about digitalization on BPM. More specifically, empirical insights on deviance and SMMs' automation needs highlights advanced compliance and automation knowledge. The descriptive and prescriptive insights enable future avenues for research, e.g., the basis for confirmatory studies. Practitioners profit from the results of either adopting the approaches for agile implementations or installing the provided and accessible artifacts.

2 Future Research

As with all research, this cumulative doctoral thesis is subject to limitations that may inspire future research activities. While all individual research articles already address their respective limitations (see Appendix V.3-V.7), this section focuses on an aggregated overview. It provides future research ideas at the intersection of BPM in the digital age, *"Process Compliance Management"*, and *"Advanced Process Automation"*.

Firstly, the investigation of future challenges, opportunities, and capability areas for BPM takes a holistic perspective. However, research article #1 presents explanatory results based on the opinions of 29 academics and practitioners. Further iterations of the study featuring different panels could focus on the effects of specific capability areas and the impact of specific technologies on BPM. This would deepen the understanding of the operationalization and importance of the capability areas. Moreover, confirmatory studies seem fruitful for validation purposes; in this case, to further analyze which capability areas drive corporate success in different settings. Confirmatory studies might also show interdependencies in terms of correlations and influences between capability areas.

Secondly, the same holds true for the research articles that analyze process deviance. Research article #2 may benefit from further exploration of process participants' or portfolio managers' perspectives on process deviations and their causes. Confirmatory studies could validate the actual impacts and significance of the reasons behind process deviance. In addition, research article #2 serves as a source for the development of a light-weighted decision-support tool for process managers. The 33 reasons could be used as checklist items to assess business processes' proneness to deviance. The use of such a tool requires further research on the importance of single reasons in various contexts. Research article #3 provides similar opportunities. Addressing the limitations of experimental settings, a real-world implementation, including the long-term assessment of changed behavior, could provide more meaningful insights and improve validity. Another interesting angle may be the analysis of different personality types and corresponding nudges. Existing research on creating digital nudges – such as the DINO model introduced by Meske and Potthoff (2017) – could be adapted to create specific nudges for the BPM domain. Moreover, the findings open confirmatory research that explains established research theories, such as behavioral economics.

Thirdly, and finally, in the area of *"Advance Process Automation"* research, article #4 could be enhanced by an analysis of dependencies between the provided prototype instantiations and the wider IT landscape of SMMs. So far, the artifacts have only been evaluated in isolated areas of the production. Moreover, the artifactual contribution offers the opportunity for more empirical work (Ågerfalk and Karlsson 2020) on mobile devices and automation within the manufacturing area.

Future studies should collect and analyze the artifacts' benefit generation in a quantitative manner. Continuing on from research article #5, one suggestion is that future studies take up this challenge and perform an intense, long-running test phase with the aim of a full evolution phase, as recommended by the ADR approach (Mullarkey and Hevner 2019). However, an intense evolution phase combined with an empirical study could quantify the realization of benefits. Another fruitful step would be to evaluate the reference architecture and processes in manufacturers not otherwise involved in the research. This would enable researchers to assess the feasibility and applicability of the architecture and processes in a broader context.

This thesis takes a holistic perspective on BPM in the digital age and closely inspects the two capability areas, *"Process Compliance Management"* and *"Advanced Process Automation"*. Both capability areas aim for process improvements and are incorporated into the core element of Methods / Information Technology. In particular, research articles #2 – #5 investigate specific perspectives on the challenges and opportunities of BPM in the digital age, and further refine the two capability areas. In conclusion, the results show that the findings of research article #1 are relevant and transferable to other research streams and to industry, particularly manufacturing. However, the remaining capability areas offer manifold research opportunities, either investigating them individually or in combination. Overall, the research articles in this thesis take an inside-out perspective and followed empirically and design-orientated research approaches. An outside-in perspective could enrich this to implement new value propositions radically. Research articles #2 and #3 offer opportunities to use positive deviations and digital nudges for new services or products. The same holds true for research articles #4 and #5, in that automated production processes and new data sources and interaction patterns enable manufacturers' innovations. Furthermore, confirmatory research should extend the descriptive and prescriptive insights of this thesis. Understanding and being able to explain the impact of digitalization will leverage new waves of technologies, which can be further implemented.

In sum, the empirical results show that digitalization materializes impact on BPM. Besides the sole reaction to digitalization, there is also huge potential to leverage improvements via digital technologies. Academia and industry will gain from further developments and should prudently keep pace with the changing conditions. However, opposed to the continuous reaction, the design and development of solutions also create valuable understanding and strive for corporate success by new products and services. Hence, this thesis encourages researchers and practitioners to continuously advance their literacy about digitalization and new upcoming emerging technologies.

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V. Appendix

1 Index of Research Articles

Research Article #1: An Exploration into Future Business Process Management Capabilities in View of Digitalization – Results from a Delphi Study

Kerpedzhiev G., König U.M., Röglinger M., Rosemann M. (2020) An Exploration into Future Business Process Management Capabilities in View of Digitalization – Results from a Delphi Study. In: *Business & Information System Engineering*.

Research Article #2: Why do Business Processes Deviate? Results from a Delphi Study

König U.M., Linhart A., Röglinger M. (2019) Why do Business Processes Deviate? – Results from a Delphi Study. In: *Busines Research.*

Research Article #3: Exploring Potentials of Digital Nudging for Business Processes

Bammert S., König U.M., Röglinger M., Wruck T. (2020) Exploring potentials of digital nudging for business processes. In: *Business Process Management Journal.*

Research Article #4: Improving Production Processes with Mobile Devices: Designing a Light-Weight Middleware for Small and Medium-Sized Manufacturers

König U.M., Röglinger M., Urbach N. (2020) Industry 4.0 and mobile devices: Improving small and medium-sized manufacturers' production. *Working paper.*

Research Article #5: Smartphone-enabled Predictive Maintenance: Development and implementation of a reference architecture and processes

Jonas C., König U.M., Röglinger M. (2020) Smartphone-enabled Predictive Maintenance Development and implementation of a reference architecture and processes. *Working paper.*

2 Individual Contribution to the Included Research Articles

This cumulative thesis consists of five research articles that build the main body of this work. All included research articles were written in teams with multiple co-authors. Thus, this section details the respective project settings and my individual contribution to each research article.

Research article #1 (Kerpedzhiev et al. 2020) was written with three co-authors – one of them works at another international research institution. All co-authors jointly designed and executed an international Delphi study for exploring future challenges and opportunities for the BPM discipline and accordingly update an established BPM capability framework. Personally, I had a crucial role in conceptualizing, executing, and elaborating as well as coding the Delphi study. Besides, I was mainly responsible for ensuring methodical rigor and analysis of the study results. In sum, I had a prominent role in each part of the project.

Research article #2 (König et al. 2019) was written with two co-authors. All co-authors jointly developed a framework for structuring and prioritizing reasons for process deviations. I was mainly involved in developing as well as evaluating a Delphi study approach by conducting and implementing six consecutive rounds of collecting insights from academic as well as industry experts via an online questionnaire. Furthermore, I was responsible for gathering the theoretical foundation and compiling the theoretical lens of the study. During the whole research process, the article benefitted significantly from the feedback of the experienced co-authors. Overall, I was substantially involved in all parts of the project.

Research article #3 (Bammert et al. 2020) was written with three co-authors. The team jointly conceptualized and elaborated on the article's content. Together, we showed the potential of digital nudging for fostering positive process deviations as encouragement for process improvement initiatives in an online experiment. I was primarily responsible for ensuring a rigorous experimental setting as well as for interpreting the results. Throughout, I was substantially involved in all parts of the project.

Research article #4 (König et al. 2020) was developed with a team of two co-authors. Being the leading author, I had a main role in conceptualizing an action design research approach and leading a consortium of six companies and two research institutions for developing software artifacts for mobile device adoption in the production area. Moreover, I was primarily responsible for evaluating the artifacts and fostering a theoretical perspective. Although the research article represents, to a large extent, my work, the two co-authors were involved in all parts of the project and helped to advance our contribution.

Research article #5 (Jonas et al. 2020) was developed with a team of two co-authors. All co-authors jointly developed a reference architecture and processes for generally implementing and using smartphone-enabled predictive maintenance. I was mainly involved in conceptualizing and evaluating the main artifacts (i.e., reference architecture and reference processes). Furthermore, I was responsible for ensuring a high-quality research approach and accordingly results. Moreover, I was involved in conceptualizing, developing, and reworking text sections throughout the article. Overall, I was substantially involved in all parts of the project.

3 Research Article #1:
An Exploration into Future Business Process Management Capabilities in View of Digitalization – Results from a Delphi Study

Authors: Kerpedzhiev G., König U.M., Röglinger M., Rosemann M.

Published in: Business & Information Systems Engineering, 2020

Abstract: Business process management (BPM) is a mature discipline that drives corporate success through effective and efficient business processes. BPM is commonly structured via capability frameworks, which describe and bundle capability areas relevant for implementing process orientation in organizations. Despite their comprehensive use, existing BPM capability frameworks are being challenged by socio-technical changes such as those brought about by digitalization. In line with the uptake of novel technologies, digitalization transforms existing and enables new processes due to its impact on individual behavior and needs, intra- and inter-company collaboration, and new forms of automation. This development led the authors to presume that digitalization calls for new capability areas and that existing frameworks need to be updated. Hence, this study explored which BPM capability areas will become relevant in view of digitalization through a Delphi study with international experts from industry and academia. The study resulted in an updated BPM capability framework, accompanied by insights into challenges and opportunities of BPM. The results show that, while there is a strong link between current and future capability areas, a number of entirely new and enhanced capabilities are required for BPM to drive corporate success in view of digitalization.

Keywords: Business process management, Capability framework, Delphi study, Digitalization

4 Research Article #2: Why do Business Processes Deviate? Results from a Delphi Study

Authors: König U.M., Linhart A., Röglinger M.

Published in: Business Research, 2019

Abstract: Despite substantial investments in business process management (BPM), every organization experiences deviant processes, i.e., processes that show different behavior than intended. Thus, process deviance is an essential topic of BPM research and practice. Today, research on process deviance is mainly driven from a computer science perspective. IT-based methods and tools (e.g., deviance mining and prediction or compliance checking) detect process deviance by comparing log data from past process instances with normative process models or execution traces of currently running instances. However, requiring process models and event logs as input, existing approaches are expensive and limited to processes executed in automated workflow environments. Further, they can only detect process deviance, not explain why it occurs. Thus, knowledge about reasons for process deviance is immature. What is missing is a systematic exploration of reasons for process deviance. Against this backdrop, we compiled and structured reasons for process deviance based on a rating-type Delphi study with more than 30 experts from industry and academia. Thereby, we chose a process manager's perspective as analytical lens, as process managers are familiar with and responsible for business processes end-to-end. We also analyzed the reasons' importance for causing deviance in routine and nonroutine processes, two process types that capture the nature of processes in terms of variation and variety. Our results contribute to the descriptive knowledge on process deviance and serve as foundation for prescriptive research

Keywords: Business Process Management, Process Deviance, Delphi Study

5 Research Article #3: Exploring Potentials of Digital Nudging for Business Processes

Authors: Bammert S., König U.M., Röglinger M., Wruck T.

Published in: Business Process Management Journal

Abstract:

Purpose - Business process improvement is vital for organizations as business environments are becoming ever more volatile, uncertain, complex, and ambiguous. Process improvement methods help organizations sustain competitiveness. Many existing methods, however, do not fit emerging business environments as they entail initiatives with long implementation times, high investments, and limited involvement of process participants. What is needed are agile process improvement approaches. The purpose of this paper is to explore the potential of digital nudging – a concept offering tools that lead individuals to better decisions – to improve business processes.

Design/methodology/approach - Using process deviance as theoretical lens, an online experiment with 473 participants is conducted. Within the experiment, business processes and digital nudges are implemented to examine whether digital nudging can mitigate the weaknesses of existing process improvement methods.

Findings - Digital nudging can influence the decisions of process participants and entail positive process deviance that leads to process improvement opportunities. Further, our research gives a first hint on the effectiveness of different digital nudges and lays the foundation for future research.

Research limitations/implications - Since exploring a completely new field of research and conducting the experiment in a synthetic environment, the paper serves as a first step towards the combination of digital nudging, business process improvement, and positive process deviance.

Originality/value - The major achievement reported in this paper is the exploration of a new field of research. Thus, digital nudging shapes up as a promising foundation for agile process improvement, a discovery calling for future research at the intersection of digital nudging and business process management.

Keywords: Business Process Improvement, Process Deviance, Digital Nudging, Online Experiment

6 Research Article #4: Improving Production Processes with Mobile Devices: Designing a Light-Weight Middleware for Small and Medium-Sized Manufacturers

Authors: König U.M., Röglinger M., Urbach N.

Working Paper

Extended Abstract: Manufacturers face several challenges stemming from digitalization. These include increased costs, the need for seamless intra- and inter-organizational integration, customer expectations of increased flexibility, and the need for traceability. The term 'industry 4.0' subsumes approaches, ideas, and technologies to address these challenges and leverage future opportunities. Larger manufacturers have already realized many benefits of digitalization by adopting new technologies in their production processes. However, small and medium-sized manufacturers (SMM), in particular, struggle to successfully implement digitalization initiatives due to limited access to knowledge, a lack of human resources, and concerns over costs (Stentoft et al. 2019). Although, the majority (approx. 95%) of enterprises worldwide are classified as small and medium-sized. One way to adopt cost-effective and easy-to-integrate digital technologies are mobile devices such as smartphones, which people now use intuitively for various purposes several times a day. Mobile devices also facilitate digital transformation as parts of large-scale socio-technical systems (Legner et al. 2017). To the best of our knowledge, there are no cost-effective, light-weight solutions that particularly address the challenges facing SMMs. Hence, we formulated the following research question: *How can SMMs improve their production processes via the use of mobile devices?*

To answer the research question, we combined industry expertise with academic knowledge in an action design research (ADR) (Mullarkey and Hevner 2019; Sein et al. 2011) and consortium research project (Österle and Otto 2010). The consortium consisting of four SMMs, two software companies, and two research institutes demonstrated the need for a light-weight, SMM-fitted industry 4.0 solution. Thereby, the Bavarian Research Foundation financially supported the team during the project phase for two years.

The project team developed and evaluated the interplay of diverse mobile device types with a middleware and client application. The approach contributes an empirically evaluated software artifact and related design principles to assist SMMs. We demonstrated that mobile devices could quickly and easily improve the production processes of SMMs. In conclusion, we formulated five general design principles that help SMMs improve their production processes by adopting mobile devices. Following the project, the key recommendations for adopting mobile devices area are: (1) Consider multiple device types, (2) Ensure platform independency, (3) Support easy configuration, (4) Separate context-specific business logic, and (5) Use intuitive user interfaces.

This project brought academia and industry together to understand SMMs' ability to realize the opportunities presented by mobile devices in their production processes. The empirical results show and examine the potential benefits of using digital technologies in production processes. As for practical implications, the software artifact can guide inexperienced SMM to realize increased production process efficiency quickly. This will lead SMMs towards initial improvements and inspire further vital updates and adaptions.

Keywords: Mobile devices, Action design research, Consortium research, Industry 4.0, Production

References:

Legner C, Eymann T, Hess T, Matt C, Böhmann T, Drews P, Mädche A, Urbach N, Ahlemann F (2017) Digitalization: Opportunity and Challenge for the Business and Information Systems Engineering Community. Business & Information Systems Engineering 59:301–308.

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Stentoft J, Adsbøll Wickstrøm K, Philipsen K, Haug A (2020) Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. Production Planning & Control 76:1–18.

7 Research Article #5: Smartphone-enabled Predictive Maintenance: Development and Implementation of a Reference Architecture and Processes

Authors: Jonas C., König U.M., Röglinger M.

Working Paper

Extended Abstract: Predictive maintenance (PdM) is a widely researched topic in the field of manufacturing. It leverages the reduction of maintenance costs by minimizing periodically scheduled maintenance tasks and unforeseen machine downtimes (vom Brocke et al. 2018). Bauer et al. (2017) and Schleichert (2017) anticipate PdM will lead to a 20% increase in the reliability of production machines and a 25% reduction in inspection costs. A successful PdM requires machine data, meaning existing machines must be replaced or upgraded.

Approximately 95% of enterprises worldwide (i.e., the majority) are small and medium-sized enterprises (SMEs). The SME, in particular, tend to postpone PdM initiatives, mainly due to the high costs and effort of creating interoperability with established and in-use machines and information systems. A cost-effective digital technology is retail smartphones, which are equipped with sensors onboard. Their built-in sensors, in particular, are a valuable source of data. One possible approach seems to use retail smartphones to collect required data (i.e., one smartphone can collect data from multiple production machines) of production machines without internal sensors. Therefore, we investigate the following research question: *How can small and medium-sized manufacturers use retail smartphones for predictive maintenance?*

To answer this research question, we developed a reference software architecture (RSwA) and reference processes to implement and use smartphone-enabled PdM. We followed an action design research (ADR) approach suggested by Sein et al. (2011) and extended by Mullarkey and Hevner (2019). Together with five manufacturers, we first developed use cases, which we translated into requirements. Based on the requirements and related literature, we developed a RSwA and associated reference processes.

We developed the RSwA as a three-layer software architecture model (i.e., presentation, application, and data) and two main components: the mobile application (MA) and a server application (SA). The MA consists of five subsystems; two are graphical user interfaces (GUI) in the presentation layer (i.e., Data collection view and Monitoring view), and three relate to functions in the application layer (i.e., Data collection, Classifier management, and Monitoring). The SA consists of six subsystems; two are GUIs (i.e., Training view and Data preparation view), and four are for functions (i.e., Data preparation, Classifier modeling, Classifier training, and Classifier export). In addition to the developed RSwA, we conceived two processes for implementing and using smartphone-enabled PdM based on the presented RSwA.

We evaluated and tested the RSwA and reference processes, including prototypes, together with two manufacturers. Overall, we achieved valuable insights in the test phase regarding the usability and the accuracy of the prototypes. The manufactures stated positive feedback regarding the RSwA and the reference processes, and all expressed great interest in pursuing the topic. Our approach combines justificatory knowledge from research on PdM and on retail smartphones as monitoring devices from a theoretical perspective. From a practical perspective, our evaluation confirms the applicability and usefulness of the RSwA and reference processes.

Keywords: Predictive Maintenance, Action Design Research, Prototype

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