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Index of Research Papers

This dissertation contains the following seven research papers, of which five are already published:

Research Paper 1

Manderscheid J, Reißner D, Röglinger M (2015) Inspection coming due! How to determine the service interval of your processes! In: Motahari-Nezhad HR, Recker J, Weidlich M (eds) Business Process Management. 13th International Conference, BPM 2015, Innsbruck, Austria, August/September 2015. Lecture Notes in Computer Science, vol 9253. Springer International Publishing, Cham, pp 19–34
(VHB-JOURQUAL 3: category C)

Research Paper 2

Hosseini S, Kees A, Manderscheid J, Röglinger M, Rosemann M (2017) What does it take to implement open innovation? Towards an integrated capability framework. Business Process Management Journal 23(1)
(VHB-JOURQUAL 3: category C)

Research Paper 3

Manderscheid J (2016) Who and why? – Insights into the governance choices for open process innovation. Working Paper. Under Revision for Journal of Information Technology Theory and Application (“revisions required”)
(VHB-JOURQUAL 3: category C)

Research Paper 4

Afflerbach P, Hohendorf M, Manderscheid J (2016) Design it like Darwin – An application of evolutionary algorithms to business process redesign. Working Paper. Submitted to Information System Frontiers[1]
(VHB-JOURQUAL 3: category B)

Research Paper 5

Linhart A, Manderscheid J, Röglinger M, Schlott H (2015) Process improvement roadmapping - how to max out your process. In: Carte T, Heinzl A, Urquhart C (eds) Proceedings of the 36th International Conference on Information Systems, Fort Worth, Texas, USA
(VHB-JOURQUAL 3: category A)

Research Paper 6

Linhart A, Manderscheid J, Röglinger M (2015) Roadmap to flexible service processes – a project portfolio selection and scheduling approach. In: Becker J, vom Brocke J, de Marco M (eds) Proceedings of the 23rd European Conference on Information Systems, Münster, Germany
(VHB-JOURQUAL 3: category B)

Research Paper 7

Lehnert M, Linhart A, Manderscheid J, Svechla M (2016) V3pm: a decision support tool for value-based process project portfolio management. In: Özturan M, Rossi M, Veit D (eds) Proceedings of the 24th European Conference on Information Systems, Istanbul, Turkey
(VHB-JOURQUAL 3: category B)

[1] The final publication is available at http://link.springer.com/article/10.1007/s10796-016-9715-1.

I Introduction

I.1 Motivation

Business Process Management (BPM) is the art and science of overseeing how work is done and performed within organizations (Dumas et al. 2013). Its origins date back to the industrial age (cf. Dumas et al. 2013; van der Aalst 2013). Since Adam Smith (1723-1790), Frederick Taylor (1856-1915), and Henry Ford (1863-1947) introduced the division of labour, the initial principles of scientific management, and the emergence of mass production, BPM as a new way of thinking found its way into the production industry. In the 1950s, supported by computers and digital communication, BPM finally affected other industries (e.g., the service industry) in their way how work is done. Based on an extensive modelling tool-kit to document and guide processes, BPM became part of information systems (IS) and, particularly, workflow management systems arose in the mid-nineties. From then until now, BPM has matured to a paradigm of organizational design with a proven impact on organizational performance (Kohlbacher and Reijers 2013). Finally, BPM is an infrastructure for effective and efficient work (Harmon 2014).

In recent years, the scientific lens of BPM has continuously shifted from a technology-focused into a holistic and principle-oriented discipline (Schmiedel and vom Brocke 2015). With its combination of knowledge from information technology (IT) and the management sciences (van der Aalst 2013), BPM is fundamental for organizational competitiveness (Kohlbacher and Reijers 2013; Schmiedel and vom Brocke 2015). To withstand the pressing need for increased productivity, operational excellence, and saving costs (van der Aalst 2013), BPM addresses operational and analytical questions. Thereby, BPM ensures optimal work performance, consistent outcomes, and takes advantage of improvement opportunities (Dumas et al. 2013). With constant attention from industry and academia (Dumas et al. 2013; vom Brocke et al. 2011), BPM's horizon has been broadened based on the early stream on controlled process execution. The present ambidextrous BPM allows to run current business operations (process exploitation) and to enable innovation on emerging business and technical opportunities (process exploration) in an integrated manner (Rosemann 2014).

As an integrated system for handling organizational performance, regulatory compliance, and service quality by managing processes (Dumas et al. 2013; Hammer 2015), BPM takes two perspectives (Rosemann and vom Brocke 2015):

On the process level, BPM intends to improve an organization's business processes (Lehnert et al. 2014; Niehaves et al. 2014). Thereby, BPM takes care of all corporate processes (Harmon 2014) and differs into core, support, and management processes according to Porter's value chain (Porter 2004). Core processes give value to one or more customer (Dumas et al. 2013; Hammer 2015).

Support processes service those core processes in terms of internal customers (Hammer 2015). Management processes are necessary to supervise both core and support processes and, thus, run the organization (Hammer 2015). However, since support and management processes have a negative value added, only the value provided by core processes results in financial return. Nevertheless, organizations seek to manage all process types on an ongoing basis by using performance indicators as critical metrics (Hammer 2015). In doing so, BPM takes measures with a positive influence on process performance that, in turn, directly contributes to an organization's goals in terms of the value contribution at the organizational level (Buhl et al. 2011).

On the management level, BPM seeks to develop BPM capabilities that establish or ensure the infrastructure for efficient and effective work and that enable more easily future process improvements (Niehaves et al. 2014). Thus, BPM takes also measures that indirectly contribute to an organization's goals (Lehnert et al. 2014).

Overall, a successful and sustainable deployment of BPM addresses at least six success factors, i.e., strategic alignment, culture, people, governance, methods, and IT. In consideration of contextual factors (cf. vom Brocke et al. 2015), these factors mainly influence the process success and contribute to an organization's goals (Figure I.1-1).

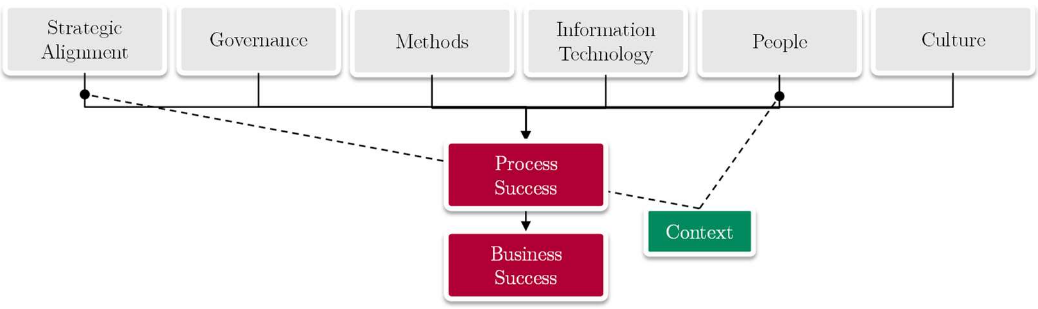

Figure I.1-1. Critical success factors of BPM on the basis of de Bruin and Rosemann (2005)

The central unit of analysis in BPM is a process. It represents a series of connected activities and events that allow for a variety of potential sequences (Dumas et al. 2013). Thus, decision points help to determine the specific order across time and place (also referred to as process path) when executing a process (Davenport 1993). Besides, a business process involves resources in terms of actors and objects. Actors usually perform the process whereas the tangible (e.g., commodities) or intangible (e.g., customer data) objects serve as in- and/or output. Finally, the combinations of activities, objects, decision points, etc. collectively lead to an outcome while forming processes with different levels of complexity (Dumas et al. 2013).

While managing end-to-end business processes as well as business performance, BPM takes a lifecycle perspective (cf. Dumas et al. 2013; Hammer 2015; van der Aalst 2013). The BPM lifecycle (Figure I.1-2) usually starts with the *identification* of the process relevant to the business problem. The documentation of this process in the *discovery* phase (with a process model as typical outcome) helps to understand the process and problem in detail. Based on this, the analysis phase seeks to identify issues and opportunities for process improvement. With a candidate set of potential remedies in mind, proposed process *redesigns* are evaluated in the next phase. The *implementation* phase, then, performs the change from the as-is process to the selected to-be-process. Once the redesigned process is running, the collection and analysis of relevant data are part of the *monitoring and controlling* phase. If new issues arise, a repetition of the lifecycle will be necessary.

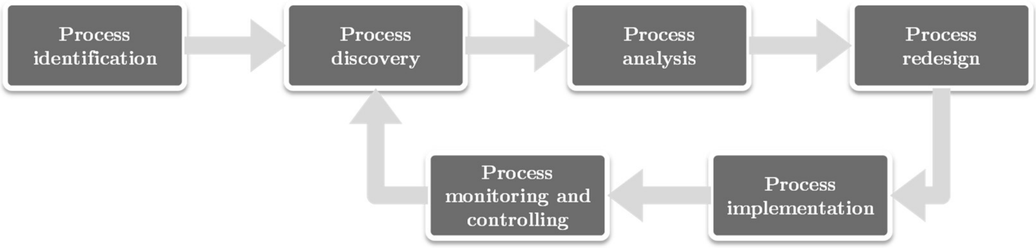

Figure I.1-2. The BPM lifecycle on the basis of Dumas et al. (2013)

Owing to the organic nature of processes and the evolving environment (Beverungen 2014), particularly continuous process monitoring and controlling as well as adequate process redesign are necessary to prevent process performance from degenerating over time or to identify new business opportunities. As a result, the process redesign is even considered as the most value-creating activity in the BPM lifecycle (Dumas et al. 2013; Zellner 2011). Global surveys and literature reviews corroborate the importance of BPM in general and business process re-design in particular (Harmon and Wolf 2014; Recker and Mendling 2016; Sidorova and Isik 2010). Due to constant attention from industry and academia, a body of knowledge and mature approaches, methods, and tools that support design, analysis, enactment, and improvement on the process level exist (Harmon and Wolf 2014; van der Aalst 2013; Vanwersch et al. 2016; Vergidis et al. 2008; Zellner 2011). Further, the BPM community has proposed several approaches that help structure and develop the corresponding capabilities on the management level (Darmani and Hanafizadeh 2013; Jurisch et al. 2014; Lehnert et al. 2014; Poeppelbuss et al. 2015; Rosemann and vom Brocke 2015; van Looy et al. 2014). Nevertheless, approaches to process improvement are still in high demand (Recker and Mendling 2016; van der Aalst 2013). In particular, there is a considerable gap between BPM in academia and industry relating to the application and usage of existing BPM technologies and approaches (van der Aalst et al. 2016). One possible reason behind this is an excessive focus on better models instead of better processes (van der Aalst et al. 2016). Therefore, and in order to bridge the gap between BPM research and BPM practice, this dissertation focuses on three challenges aligned to the improvement of business processes:

(i) Identification of processes that require redesign
(ii) Development and evaluation of new process designs
(iii) Management of redesign projects from a multi-process, multi-project, and multi-period perspective

As to the first challenge: Business processes as subsets of organizational routines underlie a drift with tendency to more complexity and worse performance caused by the evolving environment (Beverungen 2014). In daily business operations, the interaction of multiple actors and resources leads to unexpected behavior, people lose themselves in minor details, and technological and organizational changes arise (Beverungen 2014; van der Aalst and Jablonski 2000). As a result, the process execution deviates positively or negatively from the intended performance (van der Aalst and Jablonski 2000). The detection of bottlenecks, waste, and deviance on the one hand and the identification of outperforming processes on the other are the key parts of the process monitoring and controlling phase (Dumas et al. 2013; Rosemann and vom Brocke 2015). From an operational perspective, process managers and process-aware IS continuously observe process performance (Lakshmanan et al. 2012; Leyer et al. 2015). Therefore, organizations use performance indicators, target values, and admissible value ranges to control all of these process types (Leyer et al. 2015). Reasonable process performance indicators are single dimensions, e.g., time, cost, quality, and flexibility (based on their mutual interference also named as Devil's Quadrangle) (Reijers and Limam Mansar 2005), or integrated performance indicators as proposed by value-based management (VBM) (Buhl et al. 2011). From a strategic perspective, organizations observe how processes contribute to their strategic objectives (van der Aalst et al. 2016). Thus, process redesign is necessary to improve the process performance in the case of continuing missed targets or violated critical performance thresholds (Leyer et al. 2015; van der Aalst et al. 2016). As organizational resources are scarce and, thus, they are not able to analyse all processes simultaneously (nor would this be reasonable), process managers require guidance on when processes should undergo an in-depth analysis as a necessary step towards a sub-sequent redesign (Champy and Weger 2005). This challenge is addressed in Chapter II of this dissertation.

As to the second challenge: Today, organizations face constantly changing but opportunity-rich business environments, new opportunities and challenges arise every day (Kirchmer 2009). Therefore, the increase of innovation potentials, the identification of new business opportunities, and the development of new, improved, and innovative process designs are essential for the process redesign/improvement phase (Davenport 1993; Kirchmer 2009; Schmiedel and vom Brocke 2015). As this pressing need results in reduced lifecycles, most organizations cannot afford anymore to innovate on their own (Chesbrough 2003). They need new sources to explore new ideas and trends as well as to identify and effectively use distributed knowledge (Chesbrough 2003). On the one hand, open innovation (OI) as established paradigm of innovation management provides a promising concept for the effective and efficient use of internal and external knowledge. However, as many OI initiatives still fail (Chesbrough and Brunswicker 2013), new management issues arise to facilitate a successful shift. In particular, the management of collaboration, networks, and governance is still a key challenge (Rosemann et al. 2006). On the other hand, organizations need guidance and support in terms of techniques and best practices that are still scarce (Reijers and Limam Mansar

2005; Sharp and McDermott 2008; Valiris and Glykas 1999). With the methodological plethora for process redesign (Harmon and Wolf 2014; van der Aalst 2013; Vanwersch et al. 2016; Vergidis et al. 2008; Zellner 2011), industry and academia mainly focus on qualitative approaches (e.g. brainstorming) that heavily rely on human intuition, bias choices, and neglect alternatives (Hofacker and Vetschera 2001; Limam Mansar et al. 2009). The existing approaches and tools that overcome the inherent subjective vagueness are too complex or fail to support redesign (Limam Mansar et al. 2009; Nissen 2000). Chapter III of this dissertation, therefore, addresses the second challenge from various perspectives.

As to the third challenge: Process improvement is implemented via projects (Lehnert et al. 2014). Due to numerous processes within an organization and the typically large number of project opportunities, a prioritization of processes and redesign projects is necessary. For the multi-process perspective, business process architectures help reflect on interactions among an organization's processes (e.g., modularized or reused subprocesses) independent of process types (i.e., core, support, and management) (Dijkman et al. 2016; Malinova et al. 2014). For the multi-project perspective, organizations have to consider multiple interactions among IT/IS projects (e.g., mutual exclusion, predecessor/successor) and corresponding case-specific constraints (e.g., latest finishing, restricted budgets) (Liu and Wang 2011; Müller et al. 2015). Thereby, literature differs three interaction types, i.e., inter- vs. intra-temporal, deterministic vs. stochastic, and scheduling vs. no scheduling interactions (Kundisch and Meier 2011). Intra- and inter-temporal interactions affect project portfolios within one period or the sequence of project or project portfolios across several periods, respectively (Bardhan et al. 2004; Gear and Cowie 1980). Scheduling interactions reflect different starting points for different projects. In order to prioritize processes or redesign projects, existing approaches help determine the need for improvement of strategically important processes based on performance indicators or non-performance-related process characteristics (e.g., ecological, social, and cultural indicators) (Bandara et al. 2015; Lehnert et al. 2015; Leyer et al. 2015; Ohlsson et al. 2014; vom Brocke and Sonnenberg 2015). Most of the existing approaches take a single-process/single-project (Forstner et al. 2014) or a multi-process/multi-project perspective (Bandara et al. 2015; Darmani and Hanafizadeh 2013; Lehnert et al. 2014; Lehnert et al. 2015; Ohlsson et al. 2014). Whereas the first group neglects improvement opportunities owing to a narrow scope, the second group operates on a high abstraction level owing to the resulting complexity. Therefore, prescriptive knowledge toward a single-process/multi-project perspective and the effect of projects on process performance is still lacking (van der Aalst et al. 2016). This challenge is addressed in Chapter IV of this dissertation.

To sum up, the pressing need to prevent processes performance degeneration and to benefit from opportunity-rich business environments pose challenges for BPM regarding (i) the identification of processes that require redesign, (ii) the development and evaluation of new process designs, and (iii) the management of redesign projects from a multi-process, multi-project, and multi-period perspective. Therefore, this dissertation aims to overcome these challenges and to provide insights for research and practice. In the following Section I.2, the corresponding research papers are embedded in the research context and the fundamental research questions are highlighted. The subsequent Section I.3 illustrates the objectives and structure of the dissertation.

I.2 Research Context and Research Questions

The further development of BPM has to deal with the short-tem/long-term trade-off between process improvement and BPM capability development (Lehnert et al. 2014). The relevant BPM capabilities can be derived from the six factors that foster an organization's business success, i.e., strategic alignment, governance, methods, IT, people, and culture (Rosemann and vom Brocke 2015). As integral part of the framework, BPM capability development accounts for the distinct phases of the BPM lifecycle in the methods and IT factor bringing together the process and the management level. The methods factor focuses the availability of tools and techniques that support BPM activities along the whole process lifecycle (Rosemann and vom Brocke 2015). The IT factor refers to the corresponding technical support in terms of software, hardware, and IS (Rosemann and vom Brocke 2015). With their integrated view and support potential, these two factors are of particular importance in the context of BPM. In particular, a distinct focus on methods and IT capabilities can help fill the gap concerning the applicability of scientifically sound process improvement approaches that focus on processes instead of process models, while catering for the growing need for methodological support (van der Aalst 2013; van der Aalst et al. 2016). Therefore, with an excessive focus on processes, this dissertation seeks to support the management of process- and BPM-related issues of the BPM lifecycle that are associated with the most value-creating redesign activity: Through a scientific lens, this dissertation extends the BPM body of knowledge along the sequence from process monitoring and control to the planning of concrete redesign measures. It provides frameworks, models, and methods that shape the research area, particularly at the interface to innovation management, and support economic-based decisions when redesigning processes. The findings derived serve as a basis for evaluation, empirical testing, and application. From a practical point of view, this dissertation supports the prioritizing, selecting, and operationalizing of process improvement and innovation activities in line with an organization's goals. Further, it extends the quantitative toolset while reducing the bias by subjective vagueness. Regarding the methodological diversity, this dissertation strives the theoretical contributions as well as their application and usage in an integrated manner. Therefore, parts of this dissertation can be assigned to the method or IT factor solely or lie at the intersection of both factors respectively. Figure I.2-1 matches the sections of this dissertation to the corresponding factors and capability areas based on the underlying research questions and main objectives as stated below.

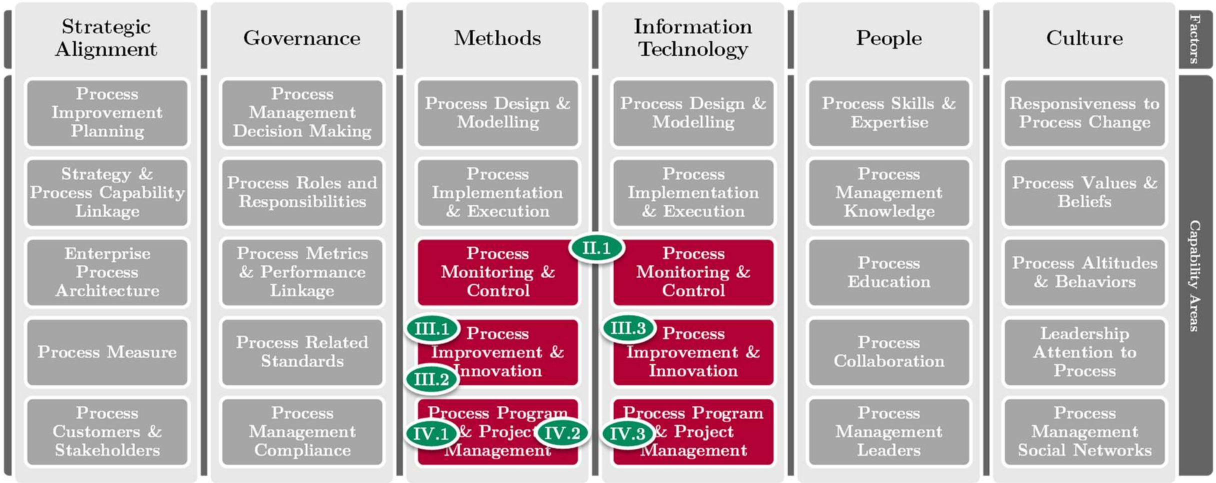

Figure I.2-1. BPM Capability Framework on the basis of Rosemann and vom Brocke (2015)

Regarding process monitoring and control, process managers require methods that provide guidance and solutions for process controlling, performance visualization, escalation management, and exception handling (Rosemann and vom Brocke 2015). However, in reality, process portfolio managers are in charge of many processes. Thus, a deep, simultaneous analysis of all processes is restricted by resource scarcity and from an economic point of view. Therefore, Section II.1 provides guidance by addressing the following research question:

How to determine when processes should undergo the next in-depth analysis to check whether they require redesign?

Once processes require redesign, BPM needs methods that facilitate the derivation of redesign ideas whose implementation, in turn, will lead to improved business processes (Rosemann and vom Brocke 2015). Therefore, organizations need BPM approaches that go beyond the control flow perspective (Recker and Mendling 2016). Model-based analysis, which may build on data gathered from process execution, supports process improvement during the redesign phase (van der Aalst 2013). A structured process to new process designs can make use of four distinct more or less analytical or creative approaches, i.e., enhancement, derivation, utilization, and design/innovation (Recker and Rosemann 2014; Rosemann and vom Brocke 2015). The process enhancement considers current practices and thinks in patterns (e.g., re-sequencing steps in a process) (Recker and Rosemann 2014). The process derivation tries to learn from other best practices (e.g., reference models, benchmarking) (Recker and Rosemann 2014). The process utilization taps into an organizations assets looking for potential practices (e.g., better use of existing resources) (Recker and Rosemann 2014). The design-led process innovation thinks disruptive to derive revolutionary process designs (Recker and Rosemann 2014). Regarding the latter, opening one's innovation process in terms of OI allows to incorporate knowledge of external sources and to increase one's innovation potential (Chesbrough 2003). However, owing to the difficulties and the high failure rate (Enkel et al. 2011; Chesbrough and Brunswicker 2013), organizations should carefully define the scope of their OI initiatives. Therefore, Section III.1 addresses the following research question:

Which capabilities should organizations consider when implementing open innovation?

Nevertheless, in the context of BPM, specific challenges concerning the process at hand as innovation problem arise. Considering open process innovation (OPI) as a management perspective on the systematic use of OI for process innovation (Niehaves 2010), there is a particular need for an appropriate BPM governance. Therefore, Section III.2 addresses the following research question:

When and why are certain forms of governance suitable in the context of OPI concerning innovation performance?

Besides, revolutionary process designs are not exclusive to the design-led process innovation approach. Other approaches could also result in revolutionary designs – either at once or by incrementally improving processes (Jurisch et al. 2014; Niehaves et al. 2011; vom Brocke et al. 2011). In doing so, organizations are able to bridge the trade-off between keeping well-performing design structures and continuously evolving new designs. Nevertheless, owing to the ever increasing complexity in today's business environment, there is a pressing need for computational support to deal with complex processes and a mass of data, to increase redesign speed, as well as to reduce uncertainty and subjective vagueness (Sharp and McDermott 2008; van der Aalst 2013; Vergidis et al. 2008; vom Brocke et al. 2011). Therefore, Section III.3 addresses the following research question:

How can organizations leverage computational intelligence to redesign their processes while accounting for the essential process elements?

The redesign ideas and measures in mind, process managers have to derive process improvement projects and to incorporate these projects to the overall organization-wide management of BPM (Rosemann and vom Brocke 2015). As a result, BPM also requires process program and project management capabilities (Rosemann and vom Brocke 2015). Thereby, it is not enough to cover the spectrum of process improvement opportunities only fragmentarily (e.g., focusing on distinct improvement dimensions, distinct process types, or on a single-process and single-project perspective). Further, an economic-based decision in line with an organization's goals requires a detailed analysis of the project effects on the process performance instead of a high level of abstraction. Therefore, Section IV.1 addresses the following research question:

Which projects should an organization implement to improve a distinct process, particularly accounting for process characteristics that reflect how work is performed and organized?

Further specific requirements exist concerning the service industry – the biggest and most strongly growing business sector in all industrial nations (Fitzsimmons et al. 2014) – owing to their susceptibility to demand uncertainty and variety. Thus, the high intrinsic need for flexible service processes let service providers heavily invest in flexibility (Neuhuber et al. 2013). However, the appropriate and economically feasible level of flexibility depends on the service process' environment (van Biesebroeck 2007). Therefore, Section IV.2 addresses the following research question:

Which flexibility projects should a service provider implement in which order to achieve an appropriate level of flexibility for its service processes in line with economic principles?

As multi-process, multi-project, and multi-period perspectives on process improvement lead to scenarios of non-trivial complexity, computational support would facilitate process managers for calculation purposes. Besides, such a tool would be a worthwhile endeavor to confirm the scientific rigor of theoretical artefacts (e.g., by implementing decision models that support project selection and scheduling for evaluation purposes) and to foster the transfer of scientific insights to practice (cf. Peffers et al. 2007). Therefore, Section IV.3 addresses the following research question:

How to provide useful and easy-to-use tool support for value-based process project portfolio management from a multi-process, multi-project, and multi-period perspective?

In all, these research questions and the resulting objectives (outlined in Section I.3) represent the framework of this dissertation and guides the research project to overcome the BPM challenges of the identification, development, and management of redesign opportunities, ideas, or projects respectively.

I.3 Objectives and Structure

The main objective of this dissertation is to contribute to the field of BPM at the interface of process- and BPM-related issues with a particular focus on process monitoring and control, process improvement and innovation, as well as process program and project management. In doing so, this dissertation seeks to identify critical processes, to derive redesign ideas, and to plan redesign projects in view of an organization's strategy. Table I.3-1 provides an overview of the dissertation's pursued objectives and its structure. Following this, Chapter II, III, and IV present the respective research papers. Chapter V concludes with a summary of the key findings and highlights possible directions for future research.

Table I.3-1. The dissertation's objectives and structure

I	**Introduction**
Objective I.1:	Pinpointing the objectives and the structure of the dissertation
Objective I.2:	Embedding the included research papers into the research context of the dissertation and motivating the fundamental research questions
II	**Identification of critical processes (Research Paper 1)**
Objective II.1:	Timing in-depth process analyses to identify critical processes and to check for redesign needs
III	**Derivation of redesign ideas (Research Papers 2, 3, and 4)**
Objective III.1:	Identifying organizational capabilities necessary to shift towards open innovation
Objective III.2:	Evaluating the effect of certain forms of governance on the success of open process innovation initiatives
Objective III.3:	Applying computational intelligence to continuously evolve new process designs while keeping well-performing design structures.
IV	**Strategic planning of redesign projects (Research Paper 5, 6, and 7)**
Objective IV.1:	Selecting and scheduling redesign projects accounting for process characteristics and performance indicators in line with economic principles
Objective IV.2:	Selecting and scheduling redesign projects accounting for the flexibility level of service processes in line with economic principles
Objective IV.3:	Providing tool support to deal with the complexity of multi-process, multi-project, and multi-period planning decisions
V	**Conclusion and Outlook**
Objective V.1:	Summarizing the key findings
Objective V.2:	Highlighting directions for future research

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II Identification of critical processes

II.1 Inspection Coming Due! How to Determine the Service Interval of Your Processes!

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Abstract *Just like cars, processes require a general inspection from time to time. As, in reality, process portfolio managers are in charge of many processes, they do not have enough resources to deeply inspect all processes simultaneously. Nor would this be reasonable from a process performance point of view. Process portfolio managers therefore require guidance on how to determine the service interval of their processes, i.e., when they should analyze which process in depth to find out whether to initiate redesign projects. Despite the profound knowledge on process improvement, monitoring, and controlling, existing approaches are only able to rank processes or redesign projects. They do not indicate when to conduct an in-depth analysis. To overcome this research gap, we propose the critical process in-stance method (CPIM) that analytically predicts after which number of executed instances a process should undergo an in-depth analysis. The CPIM combines ideas from process performance management, value-based business process management, and stochastic processes. It accounts for variations in process performance induced by the paths and tasks included in a process model as well as by the positive and negative deviance experienced during past executions. For demonstration purposes, we apply the CPIM to an approval process for loan applications from the banking industry including a scenario analysis.*

Keywords Business Process Management, Deviance, Process Decision-Making, Process Performance Management, Stochastic Processes

III Derivation of redesign ideas

Process redesign prevents process performance from degenerating over time owing to the organic nature of processes and the evolving environment. Taking a more reactive inside-out perspective, process redesign requires BPM capabilities to improve and execute efficient processes in answer to a specific problem (process exploitation). Taking a more proactive outside-in perspective, process redesign requires BPM capabilities to scan the environment as well as to assess the applicability of new opportunities to existing or totally new processes (process exploration). As a result, Chapter III addresses these both perspectives of the ambidextrous BPM and deals with the ability to run current operations as well as to enable innovation concerning emerging business and technical opportunities in an integrated manner. Section III.1 *What Does It Take to Implement Open Innovation? Towards an Integrated Capability Framework* and Section III.2 *Who and Why? - Insights into the Governance Choices for Open Process Innovation* consider the derivation of redesign ideas separated from existing process designs and focus on the source of ideas. In doing so, they rely on the wisdom of the crowd. With open innovation (OI), the idea finding process could be globally dispersed and, thus, opens up new business opportunities. Whereas Section III.1 takes a more holistic perspective to provide a structured overview of the capabilities needed when implementing OI, Section III.2 focuses on OI's ability to greatly improve process innovation and addresses the influence of BPM context factors on the innovation problem, the knowledge identification, and the governance choice. In contrast, Section III.3 *Design It like Darwin – An Application of Evolutionary Algorithms to Business Process Redesign* bears well-performing design structures in mind in any case. While inserting, replacing, or eliminating one or more process tasks, an evolutionary algorithm incrementally and automatically innovates existing process designs based on best practices derived from other process designs.

III.1 What Does It Take to Implement Open Innovation? Towards an Integrated Capability Framework

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Purpose – *In a world of ever-changing corporate environments and reduced product life cycles, most organizations cannot afford anymore to innovate on their own. Hence, they open their innovation processes to incorporate knowledge of external sources and to increase their innovation potential. As the shift towards open innovation (OI) is difficult and makes many initiatives fail, the question arises which capabilities organizations should develop to successfully implement OI. As the literature encompasses mature but isolated streams on OI capabilities, there is a need for an integrated capability framework.*

Design/methodology/approach – *This paper proposes the Open Innovation Capability Framework (OICF) that compiles and structures capabilities relevant for implementing OI. The OICF covers the outside-in and coupled processes of OI. To integrate multiple streams of the OI literature, the OICF builds on a structured literature review. The OICF was also validated in a two-step review process with OI experts from academia and industry.*

Findings – *The OICF comprises 23 capability areas grouped along the factors strategic alignment, governance, methods, information technology, people, and culture. To analyze the existing body of knowledge on OI capabilities, we compare the OICF with other OI-related capability frameworks and compile a heatmap based on the results of the literature review. We also discuss the experts' feedback on individual factors of the OICF as well as on interdependencies among these factors.*

Practical implications – *The OICF provides practitioners with a structured overview of the capabilities to consider when implementing OI. Based on the OICF, practitioners can define the scope of their OI initiatives. They can use the OICF as a foundation for prioritizing, selecting, and operationalizing capability areas as well as for deriving implementation roadmaps.*

Originality/value – The OICF is the first framework to take a holistic perspective on OI capabilities. It integrates mature but isolated research streams of OI. It helps practitioners define the scope of OI initiatives and academics gain insights into the current state of the art on OI capabilities.

Keywords Open Innovation, Capability Framework, Outside-in Process, Coupled Process

III.2 Who and Why? – Insights into the Governance Choices for Open Process Innovation

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Abstract *Today, organizations face constantly changing but opportunity-rich business environments, which underlines the need to increase innovation potentials and to identify new business opportunities. Open innovation provides appropriate mechanisms, instruments, and partnerships to systematically use both internal and external knowledge sources. While open process innovation (OPI) is a management perspective on business process management (BPM), existing approaches have paid little attention to the specific challenges of OPI problems and requirements for appropriate governance. To fill this gap, we propose a research model that examines the consequences of process complexity as well as hidden knowledge, and that extends the theoretical reasoning for when and why certain forms of governance are suitable for OPI. We specifically highlight the role of context in BPM and governance form-related characteristics, i.e., expertise, integration, size, and binding on the success of OPI initiatives in terms of effectiveness and efficiency. Our results underline the complexity of OPI problems and point to organizational complexity's influence on the hiddenness of knowledge. As a key finding, the governance choices for OPI reveal a tradeoff between effectiveness and efficiency to be addressed in future research. In particular, OPI com-munity portfolios could help to unify different stakeholders' distinct strengths.*

Keywords Business process management, Open innovation, Process innovation, Governance choice

III.2.1 Introduction

Nowadays, to explore new ideas and technological trends, to leverage globally dispersed knowledge, to increase innovation potential, and to identify new business opportunities, organizations tap into new sources in terms of open innovation (OI) (Chesbrough, 2003; Chesbrough & Brunswicker, 2013; Dodgson, Gann, & Salter, 2006; Enkel, Gassmann, & Chesbrough, 2009; Whelan, Parise, de Valk, & Aalbers, 2011). OI also has the ability to greatly improve process innovation (West & Gallagher, 2006). Open process innovation (OPI) as a management perspective is a first step to make systematically use of external knowledge for process innovation (Niehaves, 2010). Yet BPM initiatives still fail to include the relevant stakeholders (Niehaves, Plattfaut, & Becker, 2012). The management of collaboration, networks, and governance is a key challenge to BPM research and practice, for BPM in general and process innovation in particular (Rosemann, de Bruin, & Power, 2006).

Despite this pressing need for organizations to integrate internal and external knowledge via BPM collaboration (Niehaves & Plattfaut, 2011), few approaches in BPM literature have shed any light on governance-related issues in OPI. Niehaves (2010) analyzed the results of personnel resource scarcity on the involvement of external actors for BPM collaboration in the public sector. Thapa, Niehaves, Seidel, and Plattfaut (2015) examined the motivations for citizens' participation related to their expertise and demography. However, owing to their limited, field-specific scope, these approaches are not generalizable in terms of OPI governance. For this purpose, the OI literature provides further findings. OPI in particular and OI in general need a comparative analysis of governance models that exploits all possible means for search breadth and search depth concerning context characteristics and OI success (Cruz-González, López-Sáez, Navas-López, & Delgado-Verde, 2015; Felin & Zenger, 2014; Huizingh, 2011). A wide range of general measures exist for measuring OI success (Cheng & Huizingh, 2014). Different OI approaches deal with the question of the appropriate degree of openness and the human side of OI. Du Chatenier, Verstegen, Biemans, Mulder, and Omta (2010) examine competencies required for participating on OI. Du, Leten, and Vanhaverbeke (2014) evaluate the effect of OI initiatives on the financial performance of R&D projects comparing two types of OI partnerships. Felin and Zenger (2014) answer the question of the governance choice matching open and closed governance forms with hiddenness of knowledge and problem complexity. However, the OI literature reveals shortcomings concerning the business process as a subject of innovation. While process perspectives do exist, they are limited to the innovation process itself (Dreiling & Recker, 2013; Enkel et al., 2009).

In short, on the one hand, BPM collaboration addresses blurring organizational boundaries and the co-existence of internal and external process workforces, but does not sufficiently account for the opportunities of OI for process improvement. On the other hand, OI management mainly focuses on product innovation and neglects the specific characteristics of business processes in terms of the innovation problem. The distinct streams also lack an integrated view of the innovation problem and innovation outcomes. Furthermore, scholars consider OI governance forms as a whole instead of differentiating specific strengths and weaknesses. We address the following research question: *When and why are certain forms of governance suitable in the context of OPI concerning innovation performance?*

To answer this question, we propose a model of OPI-related governance choice. We examine the innovation problem in the context of BPM while linking governance forms to problem complexity, hiddenness of knowledge, and OPI performance. Thus, we draw from the theoretical reasoning of OI governance choice (cf. Felin & Zenger, 2014) and BPM context factors (cf. vom Brocke, Zelt, & Schmiedel, 2015). With our specific focus on the business process as the subject of innovation, we realign the boundaries that define the inside and outside perspectives of OI from the organization to the process at hand for OPI. According to Rosemann (2014), our contribution goes beyond pure exploitative approaches and supports the development of explorative BPM capabilities. Such understanding will provide practitioners and researchers with a set of manageable, strategic levers to control their process innovation activities.

This paper is structured as follows: In Section III.2.2, we adapt the conceptualization of OPI for our purposes by briefly reviewing on the body of knowledge about BPM, process innovation, and OI. In Section III.2.3, we examine the influence of context in BPM on problem complexity and the hiddenness of knowledge as dimensions of the innovation problem. In Section III.2.4, we bring together the distinct research streams of BPM and OI that evaluate how to make use of internal and external knowledge. In Section III.2.5, we propose our model of governance choice for OPI concerning OPI performance. After discussing the managerial implications and ideas for further research in Section III.2.6, we conclude with a summary.

Contribution:

This paper contributes to the fields of open innovation (OI) and business process management (BPM). Our findings unify and extend the familiar knowledge on OI governance choice and BPM collaboration. Our proposed model of open process innovation-related (OPI-related) governance choice provides further insights into OPI initiative management. First, we concretize the innovation problem in the context of BPM (cf. vom Brocke et al., 2015) and illustrate that it is not easy to influence a process' complexity at the time of need for innovation. Second, we consider not only the hiddenness of knowledge as a determinant of governance choice. We disclose the potentials of the organizational environment and culture to decrease hidden knowledge in advance. Third, we unify collaboration and governance detached and derive the four characteristics expertise, integration, size, and binding that allow to abstract from concrete forms. Their combination with process complexity and hiddenness of knowledge reveals a tradeoff in the ways that many existing governance forms (cf. Felin & Zenger, 2014) simultaneously provide positive and negative effects to effectiveness and efficiency as OPI performance measures. Finally, the results are relevant to practice and academia as well. With respect to OPI success, OPI needs first-hand experiences and further investigations toward governance choice that enables a comparative analysis and valuation of different governance models in terms of the compilation of OPI community portfolios.

III.2.2 From Process Redesign to Open Process Innovation

BPM is an accepted paradigm of organizational design and fundamental for organizational competitiveness (Kohlbacher & Reijers, 2013; Schmiedel & vom Brocke, 2015). BPM combines knowledge from information technology and the management sciences (van der Aalst, 2013) and takes care of all corporate processes, which subdivide into core, support, and management processes (Harmon, 2014). Taking a lifecycle perspective (i.e., process design, process implementation, process enactment, and process analysis), BPM ensures optimal work performance as well as consistent outcomes and takes advantage of improvement opportunities (Dumas, La Rosa, Mendling, & Reijers, 2013).

Since process performance drops over time owing to the organic nature of processes and the evolving environment, redesign is the most value-creating activity in the BPM lifecycle (Dumas et al., 2013; Zellner, 2011). The redesign phase combines different streams that seek to increase the effectiveness and efficiency of business processes. Van der Aalst (2013) proposed a classification into model-based and data-based process analysis. Data-based analysis supports process improvement while processes are executed by discovering bottlenecks, waste, or deviations. Model-based analysis, which may build on the results of data-based analysis, supports process improvement during redesign. Also, the most fundamental classification distinguishes between BPM approaches depending on extent of improvement into incremental and radical or evolutionary and revolutionary (Jurisch, Palka, Wolf, & Krcmar, 2014; Niehaves, Plattfaut, & Sarker, 2011; vom Brocke et al., 2011). Following this, BPM gives us the ability to run current operations (process exploitation) as well as to enable innovation concerning emerging business and technical opportunities (process exploration) in an integrated manner (Rosemann, 2014). While the professional and academic BPM community has developed mature approaches, methods, and tools to support process design, analysis, enactment, and improvement (van der Aalst, 2013), there is a pressing need to assess the potentials of (disruptive) innovation considering existing or possible new processes, in order to remain competitive (Rosemann, 2014). Since any form of innovation requires new or modified processes (Kirchmer, 2009), a process focus in an innovation initiative from the outset is critical to success (Hammer, 2005).

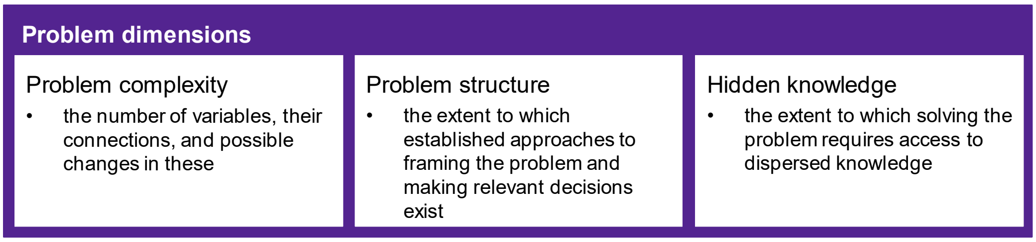
Process innovation was first postulated by Zmud (1981) and Robey (1986). Hammer (1990) and Davenport (1993) then introduced it to various industries and disciplines. Process innovation can use given technologies without heavy engineering while directly affecting people's experiences (Schmiedel & vom Brocke, 2015): For instance, the first smartphone represented a very innovative product that has led to countless ongoing process innovations. Considering that smartphones are no longer highly innovative (by exception), the potentials of process innovation as key differentiator of our times, and the opportunities of BPM as a key driver of innovation, become clear. Besides the management of innovation processes, process innovation seeks to facilitate the design of entire new process experiences incorporating new technologies as well as internal and external requirements of all involved stakeholders with focus on the business process as subject of innovation (Schmiedel & vom Brocke, 2015).

The internal and external orientations are key to process innovation success (Abdul-Hadi, Al-Sudairi, & Alqahtani, 2005; Hammer & Champy, 1993; Marjanovic, 2000). The shift from exploitative to explorative BPM will entail a change in the nature of BPM collaboration. The BPM community plays an important role to quickly convert emerging technologies into business processes (Rosemann, 2014). The stimulation, management, and exploitation of BPM networks reflects an organization's BPM maturity (Fisher, 2004; Rosemann et al., 2006). The shift from command and control to collaboration and goal-driven teamwork changed the process manager's role from a *solo entertainer* to an *orchestrator of different actors* (Niehaves et al., 2012; Rosemann et al., 2006). Blurring enterprise boundaries, especially those concerning the core processes, for instance, calls for particular governance models as well as the alignment of business strategy and OI strategy (Enkel, Bell, & Hogenkamp, 2011). Special knowledge and partnerships as well as new appropriate mechanisms and instruments that leverage external knowledge to gain new sources for innovative ideas are necessary. The needed explorative BPM capabilities can be derived from OI and the corresponding outside-in process, analogous to the BPM perspective of the same name (Enkel et al., 2009). According to Niehaves (2010), OPI is a new management perspective on process innovation. However, organizations should not only extend the systematic use of knowledge that lies outside the organizational boundaries. With a focus on the business process as subject of innovation, the distinction between internal and external innovation partners should be derived with a view to the process at hand. Following this, when talking about OPI in the context of our paper, external knowledge also occurs within an organization's boundaries, but outside the process' boundaries.

III.2.3 The Innovation Problem in the Context of BPM

III.2.3.1 The Dimensions of an Innovation Problem

Openness in terms of search breadth (i.e., the number of external sources and channels involved in OI) and search depth (i.e., the intensity of single collaborations) is a strategic choice (Bader & Enkel, 2014; Keupp & Gassmann, 2009). An efficient solution search mainly depends on the innovation problem itself (Nickerson & Zenger, 2004). Examples of general problem dimensions (see Figure III.2-1) are complexity, structure, and the need to access dispersed knowledge (Foss, Frederiksen, & Rullani, 2015). Since structure primarily relates to the existence of solution approaches for a distinct problem (Baer, Dirks, & Nickerson, 2013), it is less important in the context of innovation problems. Therefore, concerning governance choices for OPI, we consider problem complexity and hidden knowledge as key dimensions of the innovation problem, following Felin and Zenger (2014).



(Foss et al., 2015)

Figure III.2-1. The Problem Dimensions

Problems and their complexity are the starting point of solution search (Nickerson & Zenger, 2004). Problem complexity results from different sources in business organizations (e.g., technology, products, customers) (Chapman & Hyland, 2004). Analogous to NK models (with N as number of knowledge sets for a given problem, and K as the degree of interdependence among these sets), it "represents the number of issues, functions, or variables involved and the degree of relationship among these properties" (Leiblein & Macher, 2009, p. 104). Following this, simple (e.g., decomposable or low-interaction) and complex (e.g., non-decomposable or high-interaction) problems exist, as well as all other forms on the continuum between them (Leiblein & Macher, 2009). For simple problems, organizations choose a governance form with a focus on local knowledge, conducting trial-and-error search (Felin & Zenger, 2014). Organizations rely on knowledge-sharing and guide the solution search in the case of complex problems (Felin & Zenger, 2014).

Knowledge is key to finding a solution. Whether innovation problems are known or not yet known, managers must identify the right sets from existing or new knowledge sources (Nickerson & Zenger, 2004). Managers can decide for one of two ways (Felin & Zenger, 2014): They can centrally identify the knowledge or can broadcast the innovation problem. The latter results in self-selection by those affiliated with the problem field providing valuable solution proposes (Jeppesen & Lakhani, 2010). Dispersed knowledge is only a minor issue if a manager knows where to look. Difficulties arise if a manager is not aware of the relevant knowledge sources (Felin & Zenger, 2014). As a result, the ability to determine these sources in advance is of vital importance (Lopez-Vega, Tell, & Vanhaverbeke, 2016), and the hiddenness of knowledge relevant to the process innovation problem is crucial (Felin & Zenger, 2014).

III.2.3.2 The Role of Context in BPM for Process Innovation

Compared to product innovations, hard and soft organizational issues are more important for process innovations (Huizingh, 2011). For the solving of process innovation problems to be efficient and effective, one must consider the context (vom Brocke et al., 2015). To examine the attributes that define a process innovation problem from the perspective of the processes, we build on the framework of vom Brocke et al. (2015), which is suitable, since it considers both internal (e.g., process characteristics) and external (e.g., environmental characteristics) factors and allows for explorative and exploitative objectives in the goal dimension (see Figure III.2-2), and since it addresses the process, organization, and environment dimensions as contextual factors. We will now integrate and extend these factors in the specific context of process innovation initiatives.

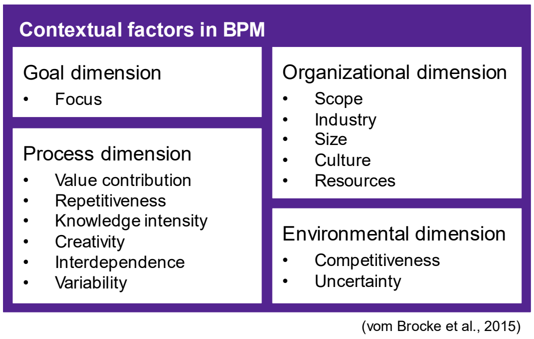


Figure III.2-2. Contextual Factors in BPM

III.2.3.2.1 The Process Dimension

Concerning the process dimension, vom Brocke et al. (2015) differentiate the factors value contribution, repetitiveness, knowledge intensity, creativity, interdependence, and variability. *Value contribution* is based on Porter's value chain (Porter, 2004) and distinguishes between core, support, and management processes. Core processes create value for customers as well as for the organization, support processes service internal customers and core processes, and management processes run the organization (Hammer, 2015). Although core processes are only valuable via co-existent support and management processes, the value contribution at the organizational level is achieved solely by the financial return of core processes (Buhl, Röglinger, Stöckl, & Braunwarth, 2011). However, from a process innovation perspective, value contribution does not matter, since BPM and thus process innovation take care of all corporate processes (Harmon, 2014). Instead, we consider *specificity* to reflect the importance of the business process under investigation within an organization. First, specific or unique processes may be highly critical for business success. Proprietary techniques and knowledge offer differentiation opportunities (Gibb, Buchanan, & Shah, 2006). Second, it is difficult to find the required skills externally for organizations with a unique mission or specialized skills (Kremic, Icmeli Tukel, & Rom, 2006). Following this, specificity does not solely reflect the processes' importance based on the three process types (i.e., core, support, and management processes), even though most of the more specific processes are likely to be core processes.

Repetitiveness considers a distinct process' execution frequency. High repetition mainly occurs with standard and routine processes that follow standard operating procedures with little variety (Lillrank, 2003). As procedures for non-routine processes are triggered by extraordinary requests (Lillrank, 2003), they are in some cases executed just once. As a result, non-routine processes are more complex and require more effort in innovation initiatives, compared to standard and routine processes (Lillrank, 2003; Schäfermeyer, Rosenkranz, & Holten, 2012). *Variability* deals with frequencies from another perspective. It considers the number of actual and possible process occurrences (Gebauer & Lee, 2008). For highly variable processes, process instances vary in the amount and the order of process activities, resulting in more or less used process activities and paths. They are close to the non-routine processes, while the more predictable processes with slight variability are equivalent to the standard and routine processes. Further, the factors knowledge intensity, creativity, and interdependence can also be seen as complexity drivers. Thus, their ranking between low and high coincidently reflects their complexity level. *Knowledge intensity* in business processes increases with the shift from optimizing structured, transactional processes to serving human-centric or knowledge work processes (vom Brocke et al., 2015). The inconsistent and non-repeatable workdays of knowledge workers mainly consist of dealing and manipulating knowledge and information with high influence on the organization (Davenport, 2015). Knowledge concerns the management (about) or content of a process (within, during) or is a result of it (from) (Işik, Mertens, & van den Bergh, 2013). Knowledge-intensive work is iterative as well as collaborative and shows no regular pattern (Davenport, 2015; vom Brocke et al., 2015). *Creativity* is very important in the context of process innovation, since it is a driver for innovativeness and competitiveness in organizations (Seidel, Shortland, Court, & Elzinga, 2015). Considering the process tasks, creativity leads to a varying level of structure, flexibility, autonomy, and personal judgment (vom Brocke et al., 2015). Creative tasks need divergent and convergent thinking at the same time, and are characterized by uncertainty and constraints (Seidel et al., 2015). *Interdependence* derives from contingency theory. One can distinguish between three types: pooled, sequential, and reciprocal interdependence (Tenhiälä, 2011). Pooled tasks have no interconnections. Their execution occurs in any combination and any order. Sequential tasks follow a specific order. Reciprocal tasks are the most complex, since any task(s) may affect multiple others. Where there are connections between tasks of different processes, there is also interdependence at the process level, which also raises the complexity. At least process maps provide an overview of all an organization's processes as well as their interdependencies, and have substantial benefits for management (Dijkman, Vanderfeesten, & Reijers, 2014; Malinova & Mendling, 2015).

We also extend this process dimension by two further factors that influence problem-solving/solution search of innovation initiatives. These are visibility and solution space structure. The limitation in the *visibility* of business processes to those outside the process or organization is a special challenge for tailoring solution search (Huizingh, 2011). While visibility to customers tends to be more restricted in manufacturing industry, customer integration is a constitutive criterion in the service industry (Fitzsimmons & Fitzsimmons, 2008). Self-services and co-creation transform customers from *passive audiences* to *active players* (Piller, 2004; Prahalad & Ramaswamy, 2000). Further, a shift from BPM to customer process management emerges to take a *customer-centered* view with a stronger outside-in focus (Rosemann, 2014; Trkman, Mertens, Viaene, & Gemmel, 2015). Nonetheless, BPM is still predominantly an organization-internal discipline; little information and details about business processes are accessible from the outside. Furthermore, a direct interface to customers often exists only for core processes, while most of the BPM work results from the support and management processes that are not visible to customers. Thus, visibility is a crucial attribute for OPI. The *solution space structure* is also relevant for problem-solving. According to research on information systems (e.g., Dennis, Valacich, Connolly, & Wynne, 1996) as well as psychology (e.g., Rietzschel, Nijstad, & Stroebe, 2007), groups that use decomposed problems generate more ideas, resulting in higher productivity and higher average originality than their counterparts who answer all-encompassing questions. Thus, Vanwersch, Vanderfeesten, Rietzschel, and Reijers (2015) distinguish three levels for the systematic exploration of innovative ideas in the context of process innovation: First, the service concept represents the relationships to customers and third parties. Second, the main process design includes all tasks intended for execution. Third, the detailed process design considers the *when*, *who*, *with what*, and *where* aspects of task execution (e.g., task order, task timing, human resources, facilities/equipment/material, information).

III.2.3.2.2 The Organizational Dimension

Concerning the organizational dimension, vom Brocke et al. (2015) differentiate the factors scope, industry, size, culture, and resources. Since different industries require different practices or differ in their adaptability regarding OI, *industry* is a critical success factor for process innovation (Škrinjar & Trkman, 2013). Particularly, industries with idiosyncrasies towards globalization, technology intensity, technology fusion, new business models, and knowledge leveraging are better suited to OI (Gassmann, 2006). *Organizational scope* is similar to the interdependence of business processes, with an extended view on organizational boundaries. Inter-organizational business processes cross these boundaries while integrating business partners. Further challenges to coordination and integration arise (Palma-Mendoza, Neailey, & Roy, 2014). *Size* matters concerning the formalization and the management of business processes. Bigger organizations tend to more bureaucracy (vom Brocke et al., 2015), while small organizations must cope with resource scarcity, which complicates management activities (Huizingh, 2011). Small organizations are at least familiar with external support in innovation initiatives, owing to their limited market reach (Lee, Park, Yoon, & Park, 2010). Organizations of all sizes need *resources*, which provide the skills needed for BPM and OPI (Rosemann & vom Brocke, 2015). Organizations at least need dedicated individuals with capabilities that can foster OI performance, such as technology mastery, personal peer leadership, social brokerage, and boundary-spanning (Habicht, Möslein, & Reichwald, 2012). Although external resources may help one to overcome resource scarcity (Kremic et al., 2006), the availability of free resources is crucial for OPI success (Niehaves, 2010; vom Brocke et al., 2015). *Culture* is also a facilitating factor for BPM initiatives (Rosemann & vom Brocke, 2015). Customer orientation, excellence, responsibility, and teamwork are four key cultural values for BPM generally (Schmiedel, vom Brocke, & Recker, 2013). In addition, OPI calls for a specific mindset with openness towards changing environments and new ways of doing things. Thus, organizations must implement an innovation culture that enables and promotes OI activities. Related capabilities are OI attitude and behavior, risk attitude towards OI, leadership attention, and IP attitude (Enkel et al., 2009; Herzog & Leker, 2010).

Finally, the organizational dimension as an internal process environment influences an organization's innovative capability at various points. However, in contrast to the process dimension, the organization dimension's factors cannot be ranked between low and high. Instead, the factors follow a nominal scale. Thus, their forms' influences on process innovation cannot be easily determined and compared.

III.2.3.2.3 The Environmental Dimension

Concerning the environmental dimension, vom Brocke et al. (2015) distinguish between the factors competitiveness and uncertainty. Competitiveness influences the pressure to innovate as well as the maximum time-to-market, while uncertainty results from market turbulence and technology turbulence (Hung & Chou, 2013; Schweitzer, Gassmann, & Gaubinger, 2011). Market turbulence describes the variation in customer demands. Technological turbulences result from changes owing to disruptive technologies. Both prevent the standardization of processes, change the needs for processing requirements, and call for agile management approaches (vom Brocke et al., 2015). Facing theses numerous challenges, organizations need responsiveness to environmental change, so that neither their market nor their technological knowledge becomes obsolete, in order to achieve and sustain competitive advantage (Bader & Enkel, 2014). A high competition environment increases the pressure to innovate. Organizations must offer new processes that result in new products and services that fit market needs faster than other market participants. An uncertain environment calls for flexibility to react fast to market changes. Process innovation can provide this.

III.2.3.3 Matching Innovation Problems and BPM Context

We have considered the process innovation problem from two perspectives. Drawing on research on solving innovation problems (Felin & Zenger, 2014) and contextual factors in BPM (vom Brocke et al., 2015), we first identified problem complexity and hiddenness of knowledge as dimensions of the innovation problem. Second, we examined the role of context in BPM, which is relevant for process innovation, while integrating and extending the contextual factors of vom Brocke et al. (2015). Based on this, we argue that matching dimensions of innovation problems and BPM context helps us get a deeper understanding of process innovation problems. This is a first step towards an OPI-specific governance choice.

While problem complexity mainly results from interdependencies between elements, interdependence is just one aspect of many, from the perspective of BPM. Process-specific problem complexity is divers. The process dimension derived from the framework of vom Brocke et al. (2015) illustrates the potential spectrum. Highly repetitive, knowledge-intensive, and variable business processes may create very complex innovation problems. Nonetheless, not all of vom Brocke et al.'s (2015) contextual factors are relevant to process innovation. We omit the distinction of processes into the categories concerning their value contribution. Instead, in our view, specificity reflects the importance of the business process under investigation within an organization and complements further situational requirements (i.e., visibility and solution space structure) as attributes of the process innovation problem. Since the problem to solve is the redesign of the process under investigation, we assign these process-related factors to problem complexity as a dimension of the innovation problem (Felin & Zenger, 2014) and refer to it as *process complexity*.

To reveal the hidden process innovation knowledge, there are three reasons for solution search (Jeppesen & Lakhani, 2010). The need for new ideas and the lack of appropriate knowledge require knowledge sources with content-related suitability. Existing knowledge sources could also be appropriate in the first case. However, the availability of these resources could result in a lack of capacity (i.e., reason 3). In other words, knowing the knowledge carriers within an organization is of no use in the case of resource scarcity. In the context of process innovation, the organizational dimension describes many attributes that influence knowledge availability from an internal and an external perspective. Size and resources determine the availability of internal capacity, which is known to the process manager. An inter-organizational scope can increase this capacity. Further, industry and culture influence innovativeness. Thus, the identification of the relevant knowledge is easier in innovative environments. Finally, the complexity of the organizational dimension should be considered in the context of governance choices for process innovation initiatives.

Competitiveness and uncertainty as environmental dimensions of the BPM context (vom Brocke et al., 2015) may also influence process innovation. Process innovation only becomes necessary owing to these environmental factors. Concurrently, these factors also increase the difficulty level for organizations to be innovative within distinct markets. Nonetheless, the environmental dimension influences process innovation independent of the available knowledge and the people involved. Thus, we can omit this dimension in the context of this paper.

Concisely (and as shown in Figure III.2-3), the problem dimensions (i.e., complexity and hidden knowledge) are at the core of innovation initiatives. Since process innovation focuses on business processes, as subject to innovation, problem complexity results from contextual factors related to processes. Contextual factors related to the organization and the environment also influence process innovation initiatives. However, only the organizational dimension explicitly affects governance choice for process innovation initiatives.

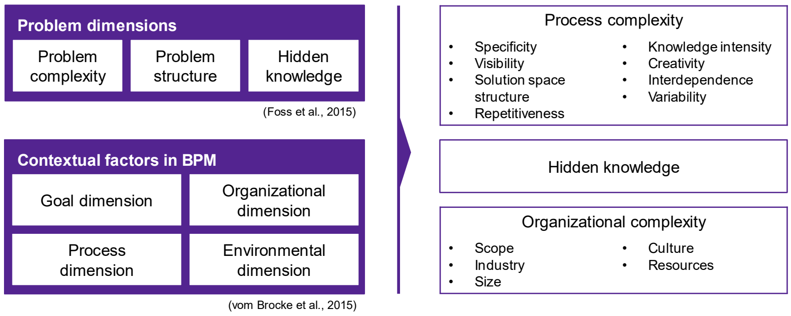
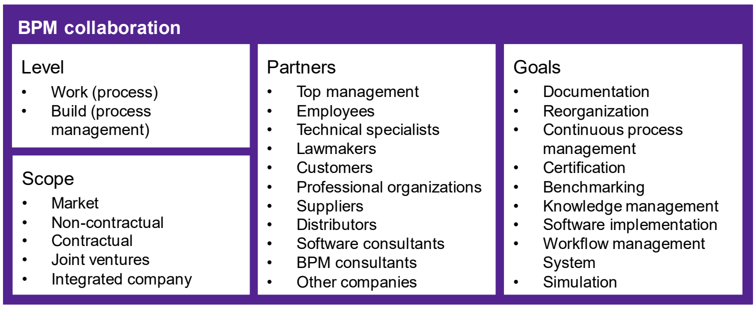


Figure III.2-3. Matching the Contextual Factors of BPM to the Innovation Problem's Dimensions

III.2.4 BPM Collaboration vs. OI Governance Forms

With the innovation problem in mind, different governance forms exist for a process manager concerning the desired search breadth and depth. These governance forms differ in their problem-solving and solution search capabilities (Foss et al., 2015). Following this, organizations must decide between specific open (e.g., partnerships, innovation contests, communities) and closed (e.g., authority-based, consensus-based hierarchy) forms of innovation, depending on the nature of their innovation problem(s) (Felin & Zenger, 2014). This selection process mainly belongs to governance choices in the context of OI, although collaboration is not new to BPM initiatives.

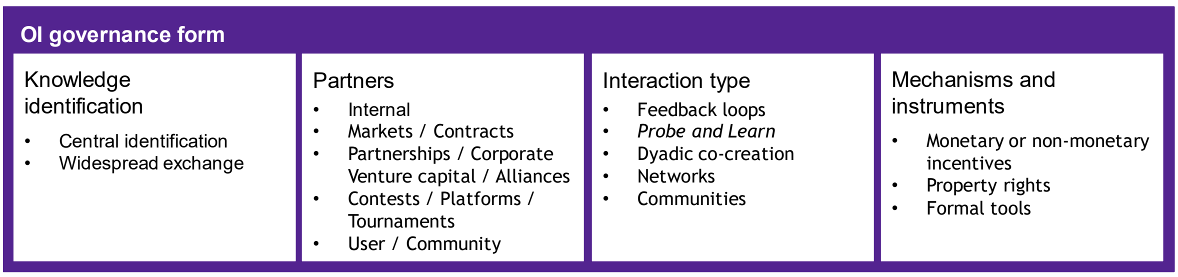
BPM collaboration concerns the ways individuals and groups cooperate in order to achieve a desired goal (Rosemann & vom Brocke, 2015). Figure III.2-4 summarizes the facets of BPM collaboration. In the form of market, network, or hierarchy (Niehaves et al., 2012), BPM collaboration includes partners from inside and outside organizational boundaries. Internal collaboration partners are found in all organizational levels, from top management, to middle management and employees, to technical specialists (Niehaves & Plattfaut, 2011). Corresponding BPM roles are Head of BPM, Process Architect, Process Analyst, Process Owner, Process Coordinator, Process Participants, or Business Experts (Dumas et al., 2013; Kettenbohrer, Kloppenburg, & Beimborn, 2015; Scheer & Hoffmann, 2015), to name a few. For external collaboration, there are two major external actor types for BPM collaboration: customers and BPM experts (Rosemann et al., 2006). There is a variety of potential BPM collaborators, including lawmakers, professional organizations, suppliers, distributors, software consultants, and BPM consultants (Niehaves & Plattfaut, 2011). BPM collaboration comprises the business process level and the BPM level (Niehaves & Plattfaut, 2011). The collaboration scope varies from market transactions over contractual agreements to integrated companies (Niehaves & Plattfaut, 2011). The collaboration goals are divers (e.g., documentation, certification, software implementation, process automation) (Niehaves & Plattfaut, 2011). Nonetheless, the focus is on process-oriented reorganization and continuous process management within supply chains agreed per contracts (Niehaves & Plattfaut, 2011). The key factors for successful collaboration are process and process management skills, experience, and social and communication skills (Rosemann & vom Brocke, 2015). There is little insight into collaboration with consultants or professionals or internal collaboration (Niehaves & Plattfaut, 2011).



(Niehaves & Plattfaut, 2014)

Figure III.2-4. Facets of BPM Collaboration

OI governance forms also cover different perspectives (see Figure III.2-5). The traditional organizational forms are hierarchical and market governance (Zenger & Hesterly, 1997). In the context of OI, they primarily correspond to more internal, closed and more external, open ways of innovation (Felin & Zenger, 2014). Examples of internal governance forms are authority-based and consensus-based hierarchy, which focus on central knowledge identification or widespread knowledge exchange, respectively (Felin & Zenger, 2014). Regarding the external governance forms, OI focuses on markets broadly (West, 2007). Several differentiators exist. The knowledge types subdivide into science-based and market-based innovation partners (Du et al., 2014). The interaction types subdivide into feedback mechanisms (e.g., feedback loops, *probe and learn*) and reciprocal innovation processes (e.g., dyadic co-creation, networks, communities) (West & Bogers, 2014). Involved parties could include suppliers, customers, competitors, and universities (Gambardella & Panico, 2014). External governance forms include markets/contracts, partnerships/corporate venture capital/alliances, contests/platforms/tournaments, and user/community innovation (Felin & Zenger, 2014). Overall, all governance forms depend on some key mechanisms to manage solution search. These are monetary or non-monetary incentives, formal tools such as processes (e.g., communication channels for knowledge-sharing), and the property rights for deriving value from innovation (Felin & Zenger, 2014; West & Bogers, 2014).



(Felin & Zenger, 2014; West & Bogers, 2014a)

Figure III.2-5. Facets of OI Governance Forms

To sum up, both BPM and OI have dealt with different forms of collaboration or governance, respectively. They both provide different forms of internal and external partnerships, such as markets, networks, and hierarchies. The BPM literature also has a strong focus on distinct roles, while the OI literature also considers efficient search mechanisms and instruments related to governance forms. Thus, OPI management should extend the common understanding of BPM collaboration by insights derived from OI initiative management. Following this, we unify both streams and differentiate between four criteria: expertise, integration, size, and binding. *Expertise* expresses the qualification levels of the individuals included in the governance form towards the OPI problem. It combines knowledge, skills, and experience and allows for a distinction between non-professionals and specialists. *Integration* covers the different forms of partnership and determines the extent of openness. A highly integrated innovation partner corresponds to a more closed governance form. *Size* represents the number of potential innovation partners within a distinct governance form. Experts are usually rare, compared to participants in innovation communities. Size also determines the knowledge identification and interaction types. For bigger groups, broadcasting and horizontal communication are the methods of choice, while selection and bilateral communication dominate in smaller groups. *Binding* covers the whole scope from contractual agreements to voluntariness. To our best knowledge, this distinction includes governance forms from the whole continuum, from collaborating with various parties to seeking out specialists with useful knowledge (West & Bogers, 2014; Zenger & Hesterly, 1997).

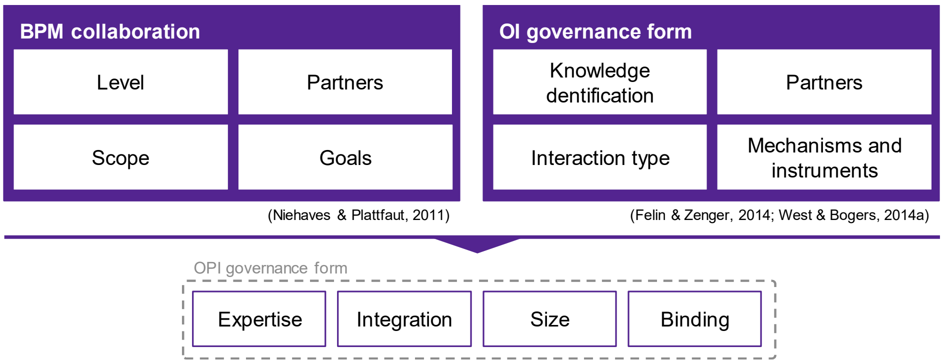


Figure III.2-6. Matching BPM Collaboration and OI Governance Forms to OPI Governance Forms

III.2.5 A Model of Governance Choice for OPI

To benefit from OI, organizations must align their OI strategy with their business strategy or model (Keupp & Gassmann, 2009; Saebi & Foss, 2015). For instance, a market defender's appropriate extent of openness differs substantially from that of an opportunity-seeking prospector (Bader & Enkel, 2014). An appropriate extent of openness, with its corresponding internal structures and processes, is essential for improving an organization's innovation performance via OI (Bader & Enkel, 2014). The literature on BPM and OI provides a useful basis for investigating governance choices for OPI initiatives. Nonetheless, both research streams focus on distinct perspectives. By combining these perspectives, we could derive further insights into OPI management. Thus, we extend knowledge by proposing a model of OPI-related governance choices (see Figure III.2-9) based on the literature review and our discussion above.

To examine the effects of context in BPM on governance choices, it is necessary to first define OPI objectives that reflect OPI initiative performance. Since there are various perspectives on OI, there are many relationships between OI and innovation performance (Cheng & Huizingh, 2014). Various scholars have examined innovation performance in terms of OI effectiveness using a wide range of measures, such as either new products or service innovativeness, financial or non-financial benefits (e.g., lower costs, more sales, shorter time to market), customer satisfaction, or the number of innovations (e.g., Cheng & Huizingh, 2014; Piller, 2004). Further approaches have considered organization performance instead of effectiveness along various variables (e.g., Chaston & Scott, 2012; Hung & Chou, 2013; Laursen & Salter, 2006). Some of those approaches have not specified organization performance in detail (e.g., Cruz-González et al., 2015; Rass, Dumbach, Danzinger, Bullinger, & Moeslein, 2013), or have focused only on a certain aspect of OI (e.g., Chesbrough & Prencipe, 2008). Even though organization performance and innovation effectiveness differ in the applied measures, both investigate an organization's ability to produce the desired innovative outcomes without wasting time, money, or resources. Innovation performance is the extent of success in achieving the goals related to an innovation (Cheng & Huizingh, 2014). Thus, we divide OPI performance into two dimensions, effectiveness and efficiency, following Piller (2004) as well as Cheng and Huizingh (2014). Effectiveness covers the market needs perspective. Innovations are valued for their novelty (new-to-market) and their ability to compete in the marketplace, creating a higher willingness to pay (fit-to-market) (Cheng & Huizingh, 2014; Piller, 2004). Efficiency considers the operating processes of solution-finding. Efficient innovation processes reduce the time from the start of a development to its launch (time-to-market) as well as all related costs (cost-to-market) (Piller, 2004). Thus, efficiency is also a valid indicator of financial performance (Cheng & Huizingh, 2014).

While the innovation problem is the reason for OPI initiatives, effectiveness and efficiency are their objectives. Following this, we link the innovation problem's dimensions to innovation performance (see Figure III.2-7). With increasing process complexity, the solution search effort (mainly for coordination and communication) in terms of efficiency also increases (Felin & Zenger, 2014). Regarding effectiveness, there is no clear relationship to problem complexity. However, the value of solutions is very sensitive to governance choice changes for complex problems (Felin & Zenger, 2014). We therefore conclude:

Proposition 1: *The complexity of the process at hand influences OPI performance. With increasing process complexity, the innovation process is more time-consuming* *and expensive (efficiency). Also, the potential value of solutions and the risk of missing market needs increase simultaneously (effectiveness).*

As an attribute of the knowledge context, a lack of relevant knowledge complicates and endangers solution search (Heiman & Nickerson, 2004). With high hidden knowledge, the identification of effective solutions that are new and fit market needs becomes a gamble. Further, highly dispersed knowledge requires costlier knowledge management practices (Heiman, Nickerson, & Zenger, 2009). In particular, investments in and the management of communication are crucial and reduce solution search efficiency. We therefore conclude:

Proposition 2: *The hiddenness of knowledge concerning the OPI problem at hand is a relevant determinant of OPI performance. With an increasing lack of relevant knowledge for solving the OPI problem, the risk of failing market needs increases (effectiveness). Also, the additional coordination efforts lead to higher costs and higher time expenditure (efficiency).*

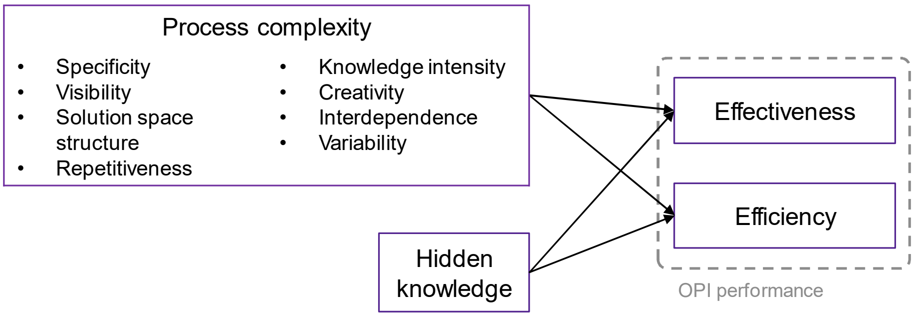


Figure III.2-7. Linking the Innovation Problem's Dimensions to OPI Performance

Based on the matching of the contextual factors of BPM to the innovation problem's dimensions, we identified organizational complexity as another factor relevant for OPI solution search. As noted, however, the availability of resources and their familiarity to process innovation can be decisively to OPI initiative success. A lack of capacity or a lack of appropriate knowledge increase the hiddenness of knowledge (Jeppesen & Lakhani, 2010). Thus, we consider organizational complexity to be a multidimensional construct, which influences the dimension of hidden knowledge (see Figure III.2-8), and conclude:

Proposition 3: *Organizational complexity influences the visibility of knowledge, while high complexity raises the hiddenness of knowledge. To minimize hidden knowledge, organizations provide sufficient capacities within and across organizational boundaries, and create an atmosphere that fosters innovative attitudes on the part of their employees and business partners.*

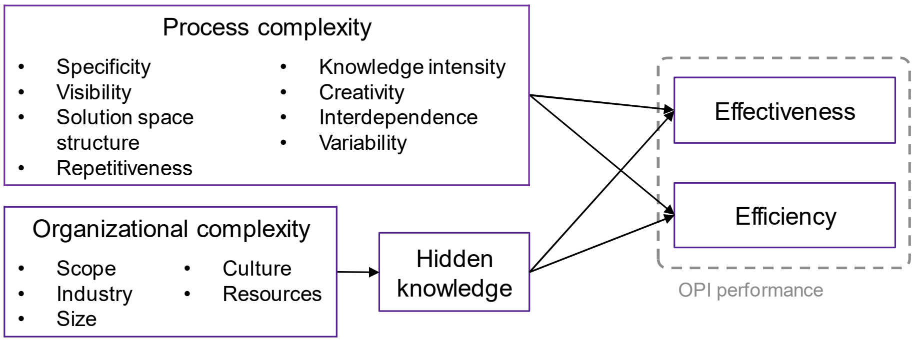


Figure III.2-8. Linking the Multidimensional Construct of Organizational Complexity to Hiddenness of Knowledge

Process complexity mainly depends on a process' characteristics as well as the process environment, and is therefore hard to influence (Schäfermeyer et al., 2012), governance choices could moderate process complexity's effects on OPI performance (see Figure III.2-9). Since experts are more effective than non-professionals, their use increases the expected value of solutions to a specific OPI problem. Since this group is smaller than innovation communities, communication costs are lower. In exchange, incentives for motivating search are required, and the property rights over solutions and knowledge need to be negotiated (Felin & Zenger, 2014). By contrast, although an idea's expected value is smaller in the case of non-professionals, the potential of breakthrough ideas from non-professionals could be higher in terms of solution variance. However, this goes along with increasing coordination efforts but low-powered incentives, which limit a search (Felin & Zenger, 2014; West & Bogers, 2014). According to Laursen and Salter (2006), there is an inverse U-shaped relationship between the extent of openness and innovation performance. Increased integration could also be beneficial. The personal suitability of OPI participants for a specific OPI problem is key to OPI performance (Thapa et al., 2015). Internal participants are more familiar with an organization's business model and processes, leading to lower communication costs owing to already embedded communication channels (Felin & Zenger, 2014). Nonetheless, external participants' potential expertise could also compensate for unfamiliarity with organizational characteristics and the costs involved. We therefore conclude as follows on governance choice's moderating effect on the relationship between process complexity and OPI performance:

Proposition 4: (expertise)	*For complex and non-decomposable OPI problems, governance forms that provide relevant expertise relating to a problem and market needs are beneficial. In contrast, for simple and decomposable OPI problems, less expertise is sufficient concerning the innovation goal, facilitating a more efficient way.*
Proposition 5: (integration)	*For complex and non-decomposable OPI problems, governance forms within organizational boundaries integrated into the processes and more familiar to the problem at hand are beneficial. In contrast, for simple and decomposable OPI problems, organizations benefit equally from internal and external support, with*

little changes to effectiveness and efficiency. External governance forms overcompensate somewhat for their lack of integration, depending on the expertise of the individuals involved.

Proposition 6: (size) *For complex and non-decomposable OPI problems, governance forms that provide a high number of potential innovation partners are beneficial regarding OPI effectiveness owing to the widespread solution search. In contrast, for simple and decomposable OPI problems, smaller groups are more time-efficient and cost-efficient owing to lower coordination efforts. Small groups overcompensate somewhat for their limited size, depending on the expertise of the individuals involved.*

Proposition 7: (binding) *For complex and non-decomposable OPI problems, governance forms with contractual commitment promise an appropriate solution of the problem due to the obligatory nature and their resulting effort. By contrast, for simple and decomposable OPI problems, organizations benefit equally from voluntary and contractually agreed collaboration. Volunteers overcompensate somewhat for their lack of commitment owing to their motivation as well as the non-needed incentives and transaction costs.*

In contrast to process complexity, hiddenness of knowledge can at least partly be influenced by controlling the organizational complexity. However, in some cases, hidden knowledge is inevitable or even desirable so as to solve an OPI problem. While hidden knowledge complicates problem-solving in terms of OPI performance, the governance choice can also act as a moderator. First, it is beneficial to widely broadcast a problem and to use mechanisms for self-selection or self-identification (Felin & Zenger, 2014). This increases the probability of self-revealed relevant knowledge in larger groups. Since organizations can mostly assess existing knowledge located within their boundaries in advance, OPI should prefer external participants if hidden knowledge is high. Nonetheless, process managers should not underestimate experts' problem-solving expertise based on their knowledge and experience. Binding in terms of compensation agreements could encourage knowledge-sharing. We therefore conclude as follows concerning governance choice's moderating effect on the relationship between hidden knowledge and OPI performance:

Proposition 8: (expertise) *To reduce the hiddenness of knowledge, governance forms with high expertise increase the likelihood of fulfilling market needs are beneficial compared to more non-professional governance forms.*

Proposition 9: (integration) *To reduce the hiddenness of knowledge, organizations broadcast an OPI problem widely to unknown, more external knowledge sources rather than the well-known, internal knowledge sources.*

Proposition 10: (size) *To reduce the hiddenness of knowledge, organizations broadcast an OPI problem widely to governance forms that provide more potential innovation partners, to increase the probability of a hit, compared to smaller groups.*

Proposition 11: (binding) *To reduce the hiddenness of knowledge, bindings with financial or non-financial incentives help to motivate knowledge carriers to uncover their ability, rather than voluntary self-selection.*

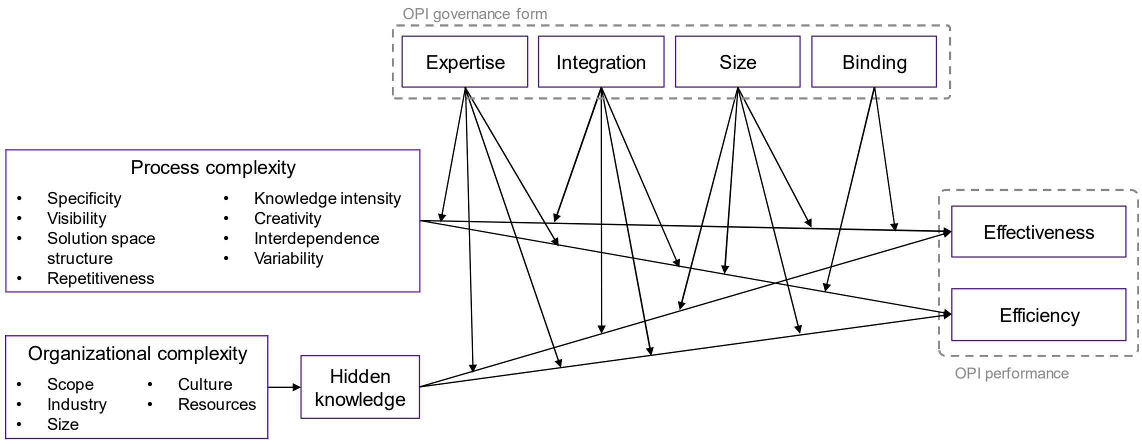


Figure III.2-9. Our Proposed Model of OPI-related Governance Choice

In short, a more differentiated analysis with a distinct focus on the process as subject of innovation extends the knowledge base concerning a problem's decomposition and the efficient solution search (Nickerson & Zenger, 2004). On the one hand, a process as innovation problem has its own specific characteristics. Process complexity is mostly a result of the process characteristics and leads to non-decomposable problems. Complexity can no longer be influenced at the time of an OPI initiative. Further, the hiddenness of knowledge is not only a result of the innovation problem, but also depends on organizational structures. Both process complexity and hidden knowledge first influence the overall OPI performance in terms of effectiveness and efficiency. On the other hand, governance choice can act as a moderator to compensate for negative effects. For process complexity, governance choice varies for simple and complex processes with regard to effectiveness and efficiency. From the knowledge perspective, governance choices are mainly relevant in the case of unknown knowledge sources, since organizations are otherwise able to choose the relevant knowledge carriers directly. However, distinct governance forms mostly improve one effect while weakening another. Thus, a differentiated consideration of governance forms' key distinctive features should form part of OPI governance and choices of suitable governance forms.

III.2.6 Implications and Future Directions

Our more differentiated analysis, with its focus on the process as subject of innovation, extends the knowledge base concerning context-specific factors. This helps to shape an effective and efficient solution search within the governance of innovations for both simple and complex problems (Felin & Zenger, 2014; Nickerson & Zenger, 2004). Finally, the research model gives further insights into the management of process innovation initiatives and provides direction to empirical testing for future research.

First, we introduced process complexity as an appropriate concretization of problem complexity in the context of OPI. In detail, process complexity is a multidimensional construct that reflects manifold process characteristics. Examples include interdependence, knowledge intensity, specificity, and creativity. The integration of these process characteristics addresses the need for hard and soft organizational issues that are key to process innovations (Huizingh, 2011). The findings help process managers in many ways. Based on the understanding of complexity in OPI initiatives, managers could estimate the cost-benefit relationship of such initiatives more precisely. It is conceivable that managers will decide on whether to start an OPI initiative in advance. Further, managers could first implement projects at the process level (cf. Linhart, Manderscheid, & Roeglinger, 2015) to establish a better base for OPI initiatives. They can at least carefully make governance choices to solve the OPI problem at hand. Nonetheless, the characteristics included in process complexity that specify business processes could overlap Thus, knowledge-intensive processes are mostly complex, mostly repeatable, and need much creativity, whereas non-knowledge-intensive processes are structured, highly repeatable, and need less creativity (Işik et al., 2013). This construct requires further research to determine the indicators that allow for measuring process complexity. Future approaches could derive ideas from the determination of complexity in the context of business process models (Mendling, 2008; Muketha, Ghani, Selamat, & Atan, 2010). It would be helpful to examine whether governance choices in OPI initiatives should consider process complexity as a single construct. One could also imagine that distinct dimensions of governance forms differ in their moderating effects, depending on the distinct characteristics that increase overall process complexity.

Second, problem-solving in the context of OPI problems should also pay attention to organizational complexity instead of focusing only on the problem and the relating governance choice. While previous research has considered hidden knowledge as part of the innovation problem, which determines governance choice (Felin & Zenger, 2014), organizational complexity as a context factor of OPI provides an additional influential factor from an organizational perspective. Organizations can create an innovative environment that helps to uncover hidden knowledge. This would simplify governance choices. Nonetheless, organizational complexity is also a multidimensional construct. Compared to process complexity, the nominal distinctive features included in this construct, such as industry (vom Brocke et al., 2015), constitute a further challenge. To foster innovativeness, organizations could invest in BPM capabilities (cf. Lehnert, Linhart, & Röglinger, 2014) as well as OI capabilities (cf. Enkel et al., 2011; Habicht et al., 2012). However, there has been little research on context-specific OI capabilities. Future research could provide further insights into the design of, or at least the influence of, organizational environment on OI generally and governance choice in particular. The resulting knowledge would be beneficial to both academia and practice.

Third, the understanding of OPI governance choices' influences on the relationship between the OPI problem and OPI performance provides further insights into the relevance of distinct governance forms. Matching BPM collaboration and OI governance forms and deriving four key distinctive features (expertise, integration, size, and binding) allow for a more detailed comparison and selection of OPI governance forms concerning the OPI problem at hand. The differentiated consideration of the derived features demonstrates the respective advantages and disadvantages. For instance, smaller groups are easier to coordinate and provide better efficiency than larger groups. In turn, these increase the potentials of breakthrough ideas. However, small groups of experts counter group efficiency, since engaging them is mostly expensive. Finally, there is no preferred governance form to a certain process complexity level and hidden knowledge. Many potential suitable participants are relevant for OPI. However, the combination of the four features reveals a tradeoff still to be solved. To address this tradeoff, research on governance choices should extend the categorization of OPI governance forms by valuation methods. As a first step, empirical studies could help to understand which governance form fits best in distinct situations. Further, future research should focus on OPI community portfolios that consist of different stakeholders with distinct strengths. Challenges will be the depth of collaboration with different innovation partners (e.g., universities, competitors), which is positively related to OPI performance and breadth of collaboration in terms of the number of different partners that has negative effects (Bengtsson et al., 2015; Cruz-González et al., 2015). The relationship between quantity and quality is also more complex than often assumed (Rietzschel et al., 2007).

III.2.7 Conclusion

In this paper, we sought to bring product innovation-centric research on OI governance choices to the context of process innovation. We offer a conceptual framework that unifies and extends the familiar knowledge on BPM collaboration and OI governance forms as well as their effects on OPI success. We specifically highlight the role of context in BPM. We then adjusted the dimensions of the innovation problem for OPI. The resulting process complexity allows for a better understanding of problem complexity in the context of processes. Further, the BPM context's organizational dimension emerged as an important influential factor on hiddenness of knowledge. The matching of BPM collaboration and OI governance choices resulted in four key distinctive features – expertise, integration, size, and binding – which describe all governance forms. Their differentiated consideration revealed a tradeoff concerning effectiveness and efficiency as OPI performance measures. Finally, the proposed model of OPI-related governance choices provides further insights into OPI initiative management concerning process complexity, hidden knowledge, and OPI performance. Nonetheless, the model does not seek to be overarching in the sense for instance that it captures all possible effects on OPI performance (e.g., the environmental dimension).

Based on the managerial and theoretical implications, our proposed model helps to determine future directions for both practice and academia. Concerning OPI success, OPI needs first-hand experiences towards context-specific governance choices and further investigations that enable a comparative analysis of different governance models in terms of the compiling of OPI community portfolios. Further insights into the multidimensional constructs process complexity and organizational complexity would also support better OPI initiative designs.

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III.3 Design It like Darwin – An Application of Evolutionary Algorithms to Business Process Redesign

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Abstract *Business process management (BPM) is an acknowledged source of corporate performance. Despite the mature body of knowledge, computational support is considered as a highly relevant research gap for redesigning business processes. Therefore, we apply Evolutionary Algorithms (EAs) that, on a conceptual level, mimic the BPM lifecycle – the most popular BPM approach – by incrementally improving the status quo and bridging the trade-off between keeping well-performing design structures and continuously evolving new designs. We begin with describing process elements and their characteristics in matrices to aggregate process information. Our EA then processes this information and combines the elements to new designs. These designs are then assessed by a function from value-based management. This economic paradigm reduces designs to their value contributions and facilitates an objective prioritization. Altogether, our triad of management science, BPM and information systems research results in a promising tool for process redesign and avoids subjective vagueness inherent to current redesign projects.*

Keywords Evolutionary Algorithms, Genetic Programming, Business Process Redesign, Business Process Management, Computational Process Management, Value-based Business Process Management

[1] The final publication is available at http://link.springer.com/article/10.1007/s10796-016-9715-1.

III.3.1 Introduction

Process orientation is an accepted paradigm of organizational design with a proven impact on corporate performance (Kohlbacher and Reijers 2013). An essential management task that organizations have to continuously execute when subscribing themselves to this proven paradigm is process redesign. It aims at increasing effectiveness and efficiency of processes by adapting the actual process design to changes in the organizational environment. Thereby, the interpretation of the term process design varies with respect to the level of abstraction. It ranges from a very high-level interpretation as an operational sequence description of executed activities and their chronological order to a very detailed interpretation as a process model which considers every possibility that may affect the way of how work is performed. In this paper, we follow an in-between interpretation of a "process blue-print" and define a process design as a description of activities, their chronological and their logical order. As process redesign is often considered as the most value-creating activity within BPM (Dumas et al. 2013; Zellner 2011), extensions of the scientific and practical tool-kit for such redesigns are still in high demand (van der Aalst 2013). Although the constant attention from industry and academia resulted in a plethora of mature approaches, methods, and tools (Harmon and Wolf 2014; van der Aalst 2013; Vanwersch et al. 2016), most redesign approaches are of qualitative nature and heavily rely on human intuition as their source of innovation (Hofacker and Vetschera 2001). Brainstorming sessions and iterative discussions are the pillars of the so-called "creative redesign approach" (Limam Mansar et al. 2009), although it is known that such discussions may bias choices and neglect alternatives. As a consequence, practical decision-makers are in deep need of computational support for the redesign act to overcome the inherent subjective vagueness (Sharp and McDermott 2008; Zellner 2011). From a scientific perspective, many scholars confirm the relevance of this research topic and denote the lack of computational redesign support as an important and current research gap (van der Aalst 2013; Vergidis et al. 2008; Zellner 2011).

Facing the ever increasing complexity of today's processes, the great need for computational redesign even accelerates. Considering the success of computational intelligence (CI) in design and optimizations problems from the business world, this paradigm seems promising to meet these needs. The abilities to cope with complex processes and a mass of data (gathered by workflow management or business intelligence systems, see van der Aalst (2013)) as well as to reduce uncertainty and subjective vagueness underlines the attractiveness of the paradigm. Further, applications of evolutionary algorithms (EA) as a prominent representative of the CI-tool-kit have already shown their potential in solving BPM problems. For example, Low et al. (2014), Richter-Von Hagen et al. (2005), and Zhou and Chen (2003) use EAs to assign resources to process activities. Vergidis et al. (2012) even utilizes the power of EAs and CI to improve process designs. However, current works do not unfold the complete potential of EAs: Their multi-objective perspectives lead to ambiguous solutions. Performance issues restrict the complexity of the process under investigation. Essential characteristics as decision nodes and the corresponding conditions are out of scope. This is why we investigate the following research question: *How can organizations leverage CI to redesign their processes while accounting for the essential process elements?*

In order to address our research question, we develop an EA-application in a broader sense and translate the real-world problem of BPM to the computational world (and back again) for solving it by CI. This allows a dynamic design of processes and supports practitioners in validating and evaluating design alternatives. Our application considers the essential elements of processes (e.g., activities, resources and their logic connectivity) which is the key challenge in the translating part. As our research method, we adopt the design science research (DSR) paradigm because the application of EAs fulfills the criteria of a valid DSR artefact type (March and Smith 1995). As justificatory knowledge, we draw from theoretical triad of CI as representative of IS research, value-based management (VBM) from management sciences and BPM as an intersecting discipline. BPM and CI provide the theoretical foundation for our application. As the evolutionary design of processes is a proven best practice in BPM, the transfer of the evolutionary way to the computational level has a sound theoretical foundation (Dumas et al. 2013). As an acknowledged theory for corporate and process decision-making, we draw from VBM to evaluate the computed redesign alternatives (Buhl et al. 2011; vom Brocke and Sonnenberg 2015).

Following the DSR methodology as per Peffers et al. (2007), this study discusses the identification of and motivation for the research problem, objectives of a solution, design and development, and evaluation. In Section III.3.2, we outline the development of computational intelligence in BPM to position the contribution of our work. In Section III.3.3, we provide relevant justificatory knowledge and derive design objectives from the business requirements (objectives of a solution). In Section III.3.4, we outline the research idea and evaluation strategy. In Section III.3.5, we introduce the EA application's design specification (design and development). Section III.3.6 reports on our evaluation activities (evaluation). We conclude in Section III.3.7 by pointing to limitations and future research possibilities.

III.3.2 Computational Intelligence in the History of BPM

BPM is "the art and science of overseeing how work is performed [...] to ensure consistent outcomes and to take advantage of improvement opportunities" (Dumas et al. 2013, p. 1). Thereby, it combines knowledge from computer and management sciences (van der Aalst 2013). In order to understand the roles of CI and to position our contribution accordingly, we give a briefly overview on the gradual evolution of BPM.

Following the historic overview on the evolution of BPM by van der Aalst (2013), the origins of BPM go back to Adam Smith (1723-1790), Frederick Taylor (1856-1915), and Henry Ford (1863-1947). The division of labour, the initial principles of scientific management, and the emergence of mass production have influenced today's BPM in its way of thinking. Since 1950, computers and digital communication evolved as the key enablers and drivers for BPM changing the way how work is done. On this digital journey towards a matured multifaceted discipline, BPM first focused on process modelling with the objectives of documenting increasingly complex processes and providing precise instructions and common agreements. Today, a plethora of systems and languages (e.g., BPMN, BPEL, UML, EPCs, etc.) form the modelling tool-kit of BPM. After a few attempts on the integration of Petri nets into office information systems in the seventies, BPM finally found its way into information systems (IS) research with the process improvement postulation from Hammer and Champy (1993) in the mid-nineties. Workflow management systems (WFMS) became available and computational BPM primarily focused on automation with little support regarding the analysis, flexibility, and management of processes.

Today, the scientific lens of BPM shifts more and more from an operational to an analytical orientation. With a broader scientific horizon, it now includes the early stream on controlled process execution and the modern stream on redesigning/improving processes. Concerning the latter mission of providing practical support on redesign projects, the BPM community has produced a variety of tools that can act as facilitators or enablers for the identification and implementation of improved process designs. However, there is still little support for computer-based and automatic generations of innovative design ideas (Bernstein et al. 2003). Scholars mainly provide qualitative techniques such as brainstorming (Kettinger et al. 1997). Although also more advanced techniques such as RePro begin to evolve (Vanwersch et al. 2015), only few works respond to the need of computational support. To list some examples: Case-based reasoning (CBR) is a first approach leveraging computational abilities to create new process designs by searching analogies to successful redesign projects implemented in the past (Min et al. 1996). The process recombinator tool by Bernstein et al. (2003) proposes new process designs based on a list of core activities. Although providing computational support for the construction and identification of new, promising designs, this tool is only semi-automatic as the selection of the most satisfactory process design is delegated to the user. The KOPer tool by Nissen (1998) identifies problematic process structures or fragmented process flows to find designs dealing with these so called process pathologies. However, the prioritization and realisation of redesigns also remains a manual task. Limam Mansar et al. (2009) build on CBR and the KOPer tool. They derive best practices for process redesign and provide empirical evidence to process managers. Besides, some applications of EAs for process redesign have emerged, presenting EAs as a promising approach to fill the gap of automated support (Low et al. 2014; Richter-Von Hagen et al. 2005; Vergidis et al. 2012; Zhou and Chen 2003). Zhou and Chen (2003) and Richter-Von Hagen et al. (2005) optimize resource assignments with regard to multiple performance objectives, whereas Richter-Von Hagen et al. (2005) have a distinct focus on knowledge-intensive processes. Vergidis et al. (2012) evaluate alternative process designs varying in size and activities due to their expected performance in fulfilling multiple objectives and resulting in a set of not-dominated designs. Low et al. (2014) use EAs to redefine starting times of activities and reallocate resources from a cost-based view. Although process performance is often considered from various perspectives like time, quality and costs, the integration of this multiplicity into EAs often comes along with performance and complexity restrictions.

To sum up, practitioners and academia have recognized the importance of tool-support for process redesign. First approaches that use artificial intelligence algorithms exist. Although IT and computational intelligence could support the design of new process alternatives more easily, more cost-effectively, quicker, more systematically, and more robust against subjective vagueness, the technical task of generating new process design is still in its infancy (Limam Mansar et al. 2009). The implementation of additional process elements, the establishment of an unambiguous redesign objectives and the ability to deal with the increasing complexity of today's processes form the next step of this research stream which we take in this paper.

III.3.3 Theoretical Background and Design Objectives

III.3.3.1 Business Process Management and Process Redesign

BPM is an integrated system for handling organizational performance, regulatory compliance, and service quality by managing processes (Dumas et al. 2013; Hammer 2015). A process as the integral part of BPM, is defined as a collection of inter-related events, activities, and decision points that involve a number of actors and objects, and that collectively lead to an outcome (Dumas et al. 2013). The specific order of activities describes how the involved actors perform their activities across time and place (Davenport 1993). Their execution may be sequential or happen in parallel. The used objects can be tangible (e.g., precious metals) or intangible (e.g., customer data) goods. They serve as in- and/or output in their original or modified forms. Both, actors and objects are also known as resources. Each set of activities in a specific order represents a process path. In the case of necessary distinctions, defined conditions decide on the right path (routing decision). Summarizing, the combinations of activities, objects, conditions, etc. from process designs with different levels of complexity. The implemented design in turn influences the overall process performance. Against this background, we define the following design objectives:

(O.1) Process Elements: To redesign processes, it is necessary to consider the key elements of processes: activities, connections and routing decisions.

Scholars and practitioners consider redesign as the most important and valuable phase of the BPM lifecycle (Zellner 2011). As companies use process redesign to keep pace with the constantly changing environment, it evolved as an everyday task (Doomun and Vunka Jungum 2008). According to Reijers and Limam Mansar (2005), companies face a technical and a socio-cultural challenge in redesign initiatives. The technical challenge relates to the identification of new process design or structures. Despite the methodological plethora for process redesign, there is still less guidance and support by means of techniques and best practices (Reijers and Limam Mansar 2005; Sharp and McDermott 2008; Valiris and Glykas 1999). The few existing approaches and the conditions to be met are too complex (Limam Mansar et al. 2009). Therefore, the tools fail to support redesign (Nissen 2000). The socio-cultural challenge originates from the organizational effects on the involved people. Many redesign initiatives struggle with organizational resistance while incorporating the newly designed processes into working practice (Wastell et al. 1994). However, only the intended use that is aligned to the strategic and operational goals of the firm may realize the value of redesign (Agarwal and Karahanna 2000). Otherwise it is worthless. To foster acceptance among practical decision-makers, it is crucial that the computational support follows a comprehensible logic in deriving new process designs. As the BPM lifecycle as the most accepted approach for process redesign relies on evolutionary and incremental procedures, we derive the following design objective:

(O.2) Evolutionary Redesign: Computational redesign should follow an evolutionary logic to be in line with known best practices and to reduce organizational resistance.

III.3.3.2 Value-Based Management

To provide concrete guidance for redesign initiatives, it is crucial to prioritize design candidates according to their expected performances (Limam Mansar et al. 2009). In general, organizations use performance indicators together with desired target values (benchmarks) and admissible value ranges (Leyer et al. 2015) to assess the performance of a process. Process performance indicators can be grouped via the Devil's Quadrangle, a framework comprising a time, cost, quality, and flexibility dimension (Reijers and Limam Mansar 2005). The Devil's Quadrangle is so-named because improving one dimension weakens at least one other, disclosing the trade-offs to be resolved during redesign. To resolve the partly conflicting nature of these performance dimensions via integrated performance indicators, the principles of VBM have been applied to process performance management (Buhl et al. 2011).

In economic research and practice, VBM has developed as the guiding paradigm of corporate decision-making (Buhl et al. 2011). VBM strives for a sustainably evolution of the firm value from a long-term perspective (Ittner and Larcker 2001; Koller et al. 2015). Thereby, it extends the shareholder value approach that was established by Rappaport (1986) and elaborated by Copeland et al. (1994) as well as by Stewart and Stern (1991). Its long-term perspective makes VBM compliant with the more general stakeholder value approach (Danielson et al. 2008). For VBM to be completely established, all corporate activities and decisions must be orientated at maximizing the firm value. As key requirements, organizations must quantify the firm value on the aggregate level and the value contributions of individual assets and decisions by regarding their cash flow effects, the time value of money, and the decision-makers' risk attitude (Buhl et al. 2011). The valuation functions that are typically used for this quantification purpose originate from investment and decision theory and consider the decision situation and the decision-makers' risk attitude (Buhl et al. 2011; Damodaran 2012).

In the last years, process decision-making devoted increasing attention to VBM (vom Brocke and Sonnenberg 2015). Its principles have found access in value-oriented (e.g., vom Brocke et al. 2010) and value-based BPM (e.g., Bolsinger 2015). Whereas, value-oriented BPM has a stronger focus on pure cash flows, value-based BPM use the valuation functions as analytical lens to compare process alternatives (Bolsinger 2015). In line with our intention to prioritize design alternatives, value-based BPM provides a suitable basis to integrate the partly conflicting nature of performance dimensions into the comprehensive value contributions (Buhl et al. 2011). Not least, ever more approaches adopt the principles of VBM to support process design in an economically well-founded manner and integrate the financial and non-financial performance effects within the central measure of process cash flows (Afflerbach et al. 2014; Bolsinger 2015; Bolsinger et al. 2015; Lehnert et al. 2014; Linhart et al. 2015a; Linhart et al. 2015b; vom Brocke et al. 2010). Thus, we define the following design objective:

(O.3) Value-Based Management: To prioritize process redesign, it is necessary to cater for cash flow effects and the time value of money. Moreover, the involved decision-makers' risk attitude must be considered.

III.3.4 Research Idea and Evaluation Strategy

In the design and development phase of our DSR project, we combine ideas from IS research, management science and BPM (as the intersecting discipline) to develop an application constructed for identifying promising redesign alternatives. BPM captures the essentials of the research problem in terms of modelling the object for optimization. CI in general and EAs in particular assist with creating new designs of the process under investigation to provide a pool of design alternatives for a deliberate choice (Keeney and Raiffa 2003). VBM complements our application by providing a suitable valuation function to prioritize the pre-constructed alternatives from the EA. The fundamentals for the integration of these diverse research directions are our programming logic for transforming processes as real-world objects into artificial, algorithmic objects and our customization of EAs towards the requirements from the business side. This triad of research disciplines is necessary as the redesign problem per se is that complex that each discipline separately cannot meet the underlying complexity.

When developing such a business application of CI, we adhere to the following blue-print: We first choose the appropriate algorithm from the broad tool-kit of CI based on theoretical reasoning (Section III.3.5.1). We then proceed with the problem representation and bring processes to the computational level based on LISt programming (LISP) and attribute matrices (Section III.3.5.2). This is the key challenge of our application as it requires the orchestration and synthesis of the three research disciplines. Finally, we customize the EA in its core functions: the creation of the initial population, the evaluation of individual organisms, the selection and reproduction mechanisms (Section III.3.5.3). Within this section, we operationalize an acknowledged valuation function used in VBM as fitness function. Complying with the requirements of VBM, the fitness function considers the cash flow and risk effects of a redesign candidate, the time value of money, and the involved decision-makers' risk attitude.

To demonstrate and evaluate our artefact, we follow Sonnenberg and vom Brocke's (2012) framework of evaluation activities in DSR. This framework considers ex-ante/ex-post and artificial/naturalistic evaluation (Pries-Heje et al. 2008; Venable et al. 2012). Ex-ante evaluation is conducted in advance, ex-post evaluation after the instantiation of the algorithm, e.g., by means of a prototypical implementation. Naturalistic evaluation demands the judgement of the artefacts in real life. To validate our design specifications, we apply an ex-post evaluation (EVAL3) that assess the usefulness of the artefact instantiations. We therefore implemented the artefact in Microsoft Excel (MS Excel) and Visual Basic for Applications (VBA). We chose MS Excel and VBA because of their popularity in corporate decision-making and ability to cope with the requirements of the artefact.

III.3.5 Computational Process Redesign

We use the concepts of CI to design an algorithm supporting the process redesign problem. To match CI capabilities and BPM requirements, we are confronted with decisions about the appropriate algorithm, about design elements and constructional aspects of the chosen CI algorithm (Koza, 1992). Design decisions cover requirements from the problem domain, its representation and objects for optimization, as well as the representation of the solutions. Constructional aspects relate to the population concept and the evaluation of solutions.

III.3.5.1 Evaluation of an Appropriate CI Approach for Process Redesign

CI provides a set of nature-inspired computational methodologies and approaches close to the human way of reasoning (Rutkowski 2008; Siddique and Adeli 2013). To find an appropriate support for process redesign, it is necessary to understand the evolutionary nature of processes and their management. Considering the BPM lifecycle, parallels to the biological evolution (Darwin 1859; Mendel 1866) become evident.

The aim of the BPM lifecycle, which is the most prominent redesign approach in practice, is analogous to the reproduction cycle in nature: an improved generation of objects. Whereas these objects are organisms (e.g., human individuals) in nature, BPM operates on processes. Their appearance are their process models and their organs are connections, activities and resources. The phases of the BPM lifecycle (Dumas et al. 2013), i.e., identification, discovery, analysis, redesign, and implementation as well as monitoring and controlling, correspond to the phases of the evolutionary reproduction, i.e. offspring, natural selection, sexual selection and reproduction as shown in the inner part of Figure III.3-1. We explain the parallels between the two concepts below:

(1) Both cycles start with an object that represents a solution according to the respective objectives – viable organisms or well-performing process designs where their performances determine survivability. If distinctive characteristics give an object an edge over competitors, it is more likely to propagate in following generations (Darwin 1859). While in nature, an organism has to compete with others about scarce resources for survival, process designs compete in terms of effectiveness and efficiency.
(2) Every object is constantly evaluated according to its goal fulfillment. Vitality and fertility of sexual partners in nature (Darwin 1859) versus performance behavior in BPM.
(3) Reproduction (or redesign in BPM) combines or replaces the best objects and modifies them via recombination and mutation (Darwin 1859; Mendel 1866). While recombination combines the genetic material of selected objects, mutation carries out random changes to create new objects. In BPM, changes in the activities and connections as genetic information produce new, potentially better performing alternatives.
(4) Both cycles result in a new generation of objects promising better adaption to the objectives. Depending on the innovation scope, one may refer to evolution or revolution. Just like new species that may evolve in nature, the BPM lifecycle could provide new processes or business models as a radical improvement.

Basically, the BPM lifecycle and the evolutionary reproduction cycle solve an optimization problem. In doing so, BPM as a relatively new discipline could benefit from the experience of other disciplines and the related developments in CI. In the set of nature-inspired computational methodologies from CI, EAs fit best the proven improvement strategy of evolutionary principles. They draw from genetic algorithms (Holland 1992), evolutionary strategies (Rechenberg 1973; Schwefel 1977), evolutionary programming (Fogel et al. 1966), and genetic programming (Koza 1992) abstracting the evolutionary reproduction cycle (Abraham 2005). Additionally, EAs represent a suitable solution to any optimization problem in the absence of any specialized technique. They provide flexibility, adaptability, robust performance, and the ability to leave local optima (in contrast to human irrationalities) making them suitable for the redesign problem. According to our theoretical reasoning, we introduce the EA approach to BPM (see outer part of Figure III.3-1). Beginning with a population of known and randomly generated objects, EAs select the best objects as "parents" for the next generations. Then, the EA recombines and mutates the selected objects following the evolutionary principles. The best objects are identified by the so called fitness function which measures the alignment of the selected objects to the overall objectives. The cycle repeats until a predefined termination and, then, returns the solutions with the highest objective value. Compared to the traditional BPM lifecycle, EAs are able to simulate many evolutionary steps at once, they are less risky and are not prone to subjective biases. Not least, first approaches in the context of BPM (Low et al. 2014; Richter-Von Hagen et al. 2005; Vergidis et al. 2012; Zhou and Chen 2003) gathered initial experience in designing the problem space and applying the mechanisms of selection, recombination, and mutation. Besides the theoretical parallels, the structural similarities of the evolutionary concepts promise to foster acceptance among practical decision-makers (see design objective O.2). Overall, we can conclude that EAs are suitable for answering the research question as they have a reasonable, theoretical underpinning for solving the redesign problem and as they are in line with our design objectives.

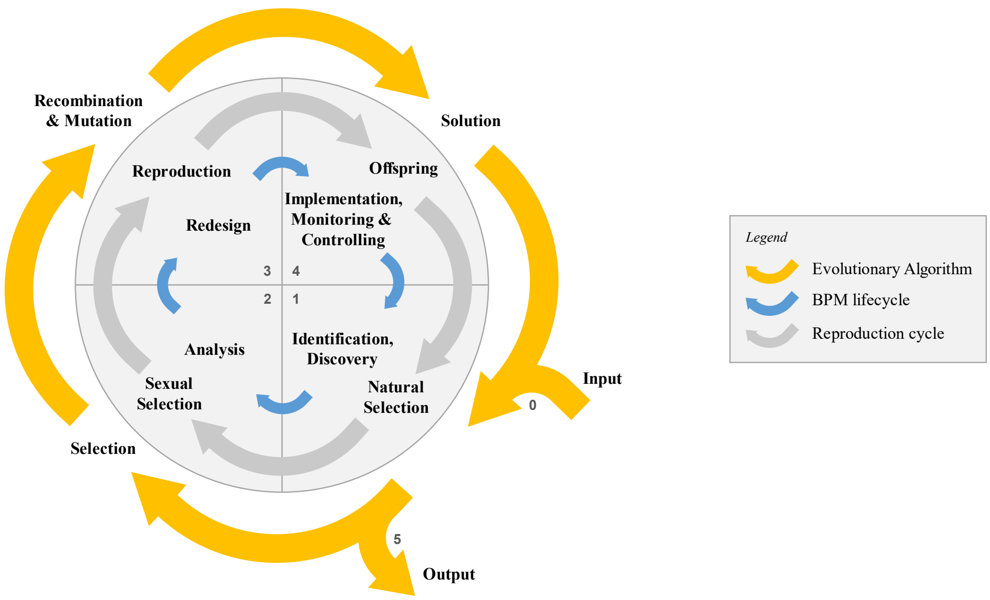


Figure III.3-1. BPM and Reprodcution in an integrated view with evolutionary algorithms

III.3.5.2 Translating From Real-world to computational world

To provide a better understanding of the design decisions – and the constructional aspects in Section III.3.5.3 – we briefly introduce an example process. We refer to this process whenever necessary and use it for evaluation purposes in Section III.3.6.2. The example is inspired by Vergidis et al. (2007) and relates to a real travel agent process. The aim of the process is to offer holiday proposals to the customers of a travel agency: The process starts with a customer enquiry containing the relevant booking information, i.e., the travel details and the price limit. The travel agent chooses from pre-configured holiday bundles and tailors a custom proposal simultaneously. On a generic level, four process activities exist where each activity can be executed in two alternative forms. The process results in a holiday proposal and the corresponding payment details. Figure III.3-2 sketches the design in BPMN notation.

III.3.5.2.1 The representation of the process components

The first and most crucial step in applying EAs to the problem domain of BPM is the solid translation of processes as real-world objects into computational objects. According to its definition, a process or its design respectively is a combination of finite objects. Following this, process redesign becomes a NP-hard problem with a highly constrained and fragmented search space as well as many local optima (Low et al. 2014). To find and assess feasible process designs, the algorithm requires not only information about the objects but also about their characteristics. Therefore, we divide process designs into their basic elements: activities, connections, and routing decisions. In order to fulfill design objective O.1 requiring the implementation of these basic elements, we introduce five matrices: the *activity-attribute matrix*, the *resource-attribute matrix*, the *activity-input matrix*, the *activity-output matrix*, and the *activity-process-attribute matrix*.

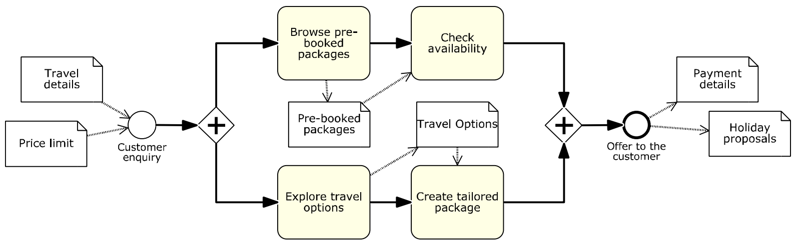


Figure III.3-2. Travel Agent Process

The first two matrices describe the attributes of activities and resources. The *activity-attribute matrix* is a library of possible activities available for process redesign. The activities in the rows (represented by the variable a_x) are completely described by their functions and economic attributes in the columns. Functions describe activities on a capability level. Although activities may fulfill the same function within a process i.e. they produce the same output, they may carry out their function differently, e.g., they may vary in the required resources. Thus, activities fulfilling the same function provide the same output with different inputs and represent alternatives. The attributes assign value contributions to activities and are required for process evaluation in later stages. As typical for VBM, we describe the efficiency of activities by expected cash flows $\mu_{a_x} = E\left[\widetilde{CF}_{a_x}\right]$ and the process risk by the variance of cash flows $\sigma_{a_x}^2 = Var\left[\widetilde{CF}_{a_x}\right]$. Both distribution parameters may be gathered from historical data or expert estimates. Figure III.3-3 (left) shows the activity list for our travel agent process. In contrast to the original process from Vergidis et al. (2007) who measure the performance of activities by time and quality, we use the integrative measure of expected cash flows and added information about the variance as Vergidis et al. (2007) did not provide this.

The *resource-attribute matrix* lists all resources that could be used during process execution. In general, most resources are used or produced by activities. However, there also exist input that is not produced by process activities (so-called process input which is externally provided prior to execution, e.g., employees or machines) and output which is not demanded by another activity (process output as the result of the complete process execution). In our example, the travel details and the price limit derived from the customer enquiry represent the process input, whereas the holiday proposals and the payment details are the process output. The *resource-attribute matrix* denotes resources (represented by the variable r_x) in the rows as process input or output and assigns economic attributes in the columns (see Figure III.3-3, right). If a resource is denoted as process input, the total cash outflows required for the provision of the resource is the corresponding economic attribute from VBM. If a resource is denoted as process output, the total cash inflows resulting from selling the output or from internal charges constitute possible economic attributes. As the process input of the travel agent process is customer information, the required cash outflows equal zero. For the process output, the travel agency charges an administration fee. Further resources, i.e., pre-booked packages and travel options, are necessary to depict a proper sequence flow. As these resources are neither process input nor process output, they do not need economic attributes.

Activity-Attribute Matrix

No.	Function	μ_{a_x}	$\sigma^2_{a_x}$
a_1	Browse pre-booked packages (PBP): Search from brochures	-1	0,30
a_2	Browse pre-booked packages (PBP): Search company intranet	-7	14,82
a_3	Explore travel options (TO): Browse past cases	-4	4,84
a_4	Explore travel options (TO): Explore new options	-23	160,02
a_5	Check availability: Via intranet/e-mail	-29	254,40
a_6	Check availability: Via phone/post	-20	121,00
a_7	Create tailored package: Use specific software	-4	4,84
a_8	Create tailored package: Combine options manually	-25	189,06

Resource-Attribute Matrix

No.	Description	Type	Process Input	Process Output	Price
r_1	Travel details	Information	Yes	No	0
r_2	Price limit	Information	Yes	No	0
r_3	Pre-booked Packages	Information	No	No	0
r_4	Travel options	Information	No	No	0
r_5	PBP: Holiday proposals	Information	No	Yes	20,00
r_6	PBP: Payment details	Information	No	Yes	25,00
r_7	TO: Holiday proposals	Information	No	Yes	20,00
r_8	TO: Payment details	Information	No	Yes	25,00

Figure III.3-3. Activities and resources of the travel agent process

The other matrices describe the relationships of objects and the control flow of the process. The latter allows for sequential, parallel, and disjunctive executions of activities (represented by gateways in modeling notations such as BPMN). The *activity-input* and *activity-output* matrices represent the logical connectivity of activities in terms on an input-output-relationship (e.g., the resource r_1 is the output from a_1 and the input for a_2). They link the activities in the rows with the required inputs / produced outputs in the columns. This information is crucial to ensure proper resource flows through the process design. According to process input and output, not all resources are both input and output in the same process design. The two left tables of Figure III.3-4 show the input-output-relationships of activities and resources for the chosen example. One can see the different alternatives for specific inputs and outputs. As a_1 and a_3 use the same input while creating differing outputs, the information in these matrices already illustrate potential, parallel executions. On a technical level, these matrices implement logical restrictions to our optimization problem: A process design is only feasible if the input for each executed activity has been provided as process or activity input in advance.

In the case of exclusive splits, routing decisions conditioned to the incoming sequence flow are required regarding which activity out of many alternatives will be executed. From a VBM perspective, conditions influence the efficiency and the risk of the process, making the implementation of execution probabilities for activities mandatory (Bolsinger et al. 2015). Focusing on data-based conditions, all process attributes known in advance or derived from execution could represent a differentiating factor. The *activity-process-attribute matrix* maps such process attributes (represented by the variable d_x) in the rows to the activities in the columns to determine under which circumstances the process is routed over a distinct activity. A process attribute is further specified by its decisive values (represented by the variable v_{x_y}) and the corresponding execution probabilities. The representation of the execution probabilities and the decisive values in turn depend on the scale of measurement of the process attribute. The matrix lists all possible decisive values and corresponding execution probabilities. For ordinal and a nominal attributes, the value range and the discrete probability distributions are entered directly. As interval scaled attributes result in continuous probability distribution, the matrix divides the value ranges into intervals and assigns the execution probabilities accordingly. In order to calculate these execution probabilities, the expected value and the standard deviation of the density function are sufficient. The distribution data may be gathered analogous to the determination of economic attributes on the basis of historical data or expert estimates. As Vergidis et al. (2007) do not consider exclusive splits, we add hotel category as process attribute for routing decisions for demonstration and evaluation purposes. According to the right table in Figure III.3-4, a_7 and a_8 would not be alternatives any more as both do not cover all required attribute values.

Activity-Input Matrix

	r_1	r_2	r_3	r_4
a_1	1	1	0	0
a_2	1	1	0	0
a_3	1	1	0	0
a_4	1	1	0	0
a_5	0	0	1	0
a_6	0	0	1	0
a_7	0	0	0	1
a_8	0	0	0	1

Activity-Output Matrix

	r_3	r_4	r_5	r_6	r_7	r_8
a_1	1	0	0	0	0	0
a_2	1	0	0	0	0	0
a_3	0	1	0	0	0	0
a_4	0	1	0	0	0	0
a_5	0	0	1	1	0	0
a_6	0	0	1	1	0	0
a_7	0	0	0	0	1	1
a_8	0	0	0	0	1	1

Activity-Process-Attribute-Matrix

Process Attribute	Hotel Category (d_1)				
Attribute Form	★	★★	★★★	★★★★	★★★★★
Probability	2,5%	17,5%	50%	25%	5%
	v_{1_1}	v_{1_2}	v_{1_3}	v_{1_4}	v_{1_5}
a_1	1	1	1	1	1
a_2	1	1	1	1	1
a_3	1	1	1	1	1
a_4	1	1	1	1	1
a_5	1	1	1	1	1
a_6	1	1	1	1	1
a_7	1	1	1	1	0
a_8	0	0	0	0	1

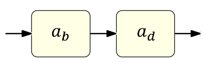
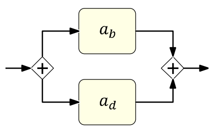
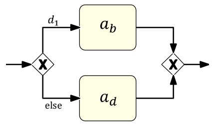
Figure III.3-4. Activities in relation to resources and process attributes.

III.3.5.2.2 The representation of the process design

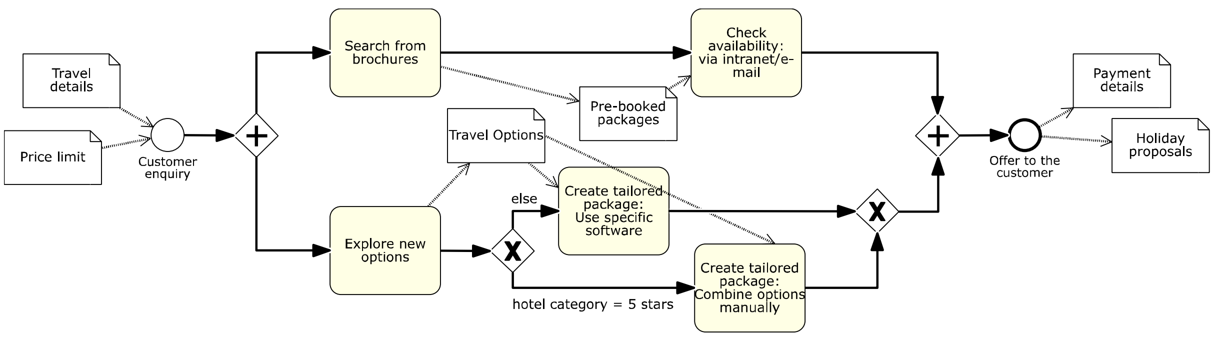
After having structured the required information about the basic elements of a redesign problem, we now elaborate the computational representation of a complete process design. As we pay attention to a communicative human-machine interface, we apply a Polish notation (also called "prefix notation") and a recursive, depth-first representation. In doing so, the processing of nested lists starts from the left hand side, similar to functional notations in MS Excel and LISP. The latter has already proven to serve many optimization problems (Koza 1992).

Following the resource perspective and to ensure proper resource flows, a process design always begins with the process input and ends with the process output represented by the variable PI or PO respectively. In between, the activities a_x and their logical connections describe the sequence flow. As mentioned above, these connections can have three different patterns: sequential, parallel and disjunctive. Sequences consist of two activities which have an input-output-relationship. In terms of programming, we write sequences where activitiy a_d follows activity a_b as an enumeration: a_b, a_d. In order to describe a parallel execution of activities, we follow a prefix notation with resemblance to the AND-function in MS Excel: $AND(a_b; a_d)$. Please note that a feasible process design requires input to execute both activities. Otherwise, the design cannot produce the desired process output. To model an exclusive split and the underlying routing decision about one out of two activities based on condition c_x, we apply the prefix XOR similar to the if-function in MS Excel: $XOR(c_x; a_b; a_d)$. The programming of conditions, in turn, requires information about the distinctive process attribute d_x and a decisive value v_{c_x} out of the possible value range from the *activity-process-attribute matrix* as well as a relational operator o. Technically, we use the following notation: $c_x = d_x\left(v_{c_x}; o_{c_x}\right)$. To conclude a process design, we surround it with angle brackets. Table III.3-1 summarizes the basic patterns of connections and activities our EA application is able to process.

Table III.3-1. Basic patterns of activity combinations.

Combination Form	Sequence	Concurrency	Exclusive split
EA notation	a_b, a_d	$AND(a_b; a_d)$	$XOR\left(d_1\left(v_{c_1}; o_{c_1}\right); a_b, a_d\right)$
BPMN 2.0 notation			

Basically, any combination of those patterns, also nested combinations, may appear in process designs. Figure III.3-5 provides such a complete process design based on our modified example. Starting from the left, PI provides the process input r_1 and r_2 for activity a_1 as well as activity a_4. Activity a_8 gets executed in process instances where the decisive characteristic "hotel category" is 5-star. For the process output, both parallel sequence flows have to be finished first. The bottom line shows the corresponding EA notification.



EA notification	$< PI, AND\left(a_1, a_5; a_4, XOR\left(d_1\left(v_{1_5}; =\right); a_8; a_7\right)\right), PO >$

Figure III.3-5. Example process in EA notification

III.3.5.3 Customizing an EA

In the following section, we leverage the flexibility of EA algorithms. Generally, EAs benefit from the exploitative and explorative character of the underlying selection and reproduction mechanisms, making it especially appealing business problems. In order to tailor EA functionalities to our redesign problem at hand, we customize the instantiation of the initial population, apply two kinds of selection and three types of reproduction mechanisms.

III.3.5.3.1 The generation of the initial population

As proper initial populations are not biased towards areas in the problem space and approach the problem space from various directions, we compose the initial population as combinations of the status quo design and random selections of activities. The status quo design is the process as it is currently implemented and serves as a baseline for the best known solution. All other process designs created in an EA run have to compete with the status quo design as a known feasible and practicable solution. Random selections create new process designs by randomly choosing a predefined number of activities from the *activity-attribute matrix* to enhance the diversity of the initial population. The size of the initial population and the following generations need to be set accordingly to the focal process. Thereby, smaller sizes have performance advantages but they more likely returns local optima. In order to illustrate our concept of initial populations, we depict an example for the travel agent process in Table III.3-2. The population size equals 5 and the number of random activities is set equal to 4. The latter specification determines the size of the generated designs.

Table III.3-2. Initial Population

$< PI, AND\left(a_1, a_5; a_4, XOR\left(d_1\left(v_{1_5};=\right); a_8; a_7\right)\right), PO >$	*(Status quo)*
$< PI, a_1, a_2, a_3, a_4, PO >$	
$< PI, a_1, a_4, a_6, a_8, PO >$	
$< PI, a_1, a_3, a_4, a_7, PO >$	
$< PI, a_3, a_6, a_7, a_8, PO >$	

III.3.5.3.2 Ensuring feasible process designs by a repair mechanism

Random selections of activities rarely constitute a feasible process design, where feasibility depends on the design's ability to produce the requested process output. As infeasible solutions are less likely to provide material for producing feasible successors and as infeasible process designs will never be put into practice, we construct a repair mechanism that ensures the desired feasibility of the created solutions.

The repair mechanism operates on an activity list, e.g., the random selection of activities in the case of the initial population. It proceeds recursively and starts with the process output. If none of the activities in a design provides the process output, the repair mechanism randomly selects an activity out of the *activity-attribute matrix* that fulfils this requirement. Step by step, it determines all activities contributing to the production of the process output by either providing inputs for following activities in the resource flow or by providing the process output. Besides, feasibility requires the complete coverage of present process attributes. As activities may only relate to a distinct selection of process attributes, the repair mechanism repeats these adding steps until all forms of the attributes can be processed. If a selected activity cannot get executed due to the missing input, the repair mechanism equivalently adds an appropriate activity from the library. Moreover, it erases activities that do not contribute to the production of the process output and finally returns a list of activities for a feasible process design.

Building on this master list of a feasible design, the repair mechanism arranges the activities with respect to their input-output-relationships to a process design following pre-defined rules: First, a direct input-output-relationship of activities leads to a sequence. Second, the repair mechanism arranges two or more activities using the same input and producing different output in parallel. Third, two or more activities with identical input-output-relationships but different coverages of process attributes result in an exclusive split. Thereby, the sequence flow splits with respect to all relevant process attributes. In the case of overlapping activity-process-attribute-relationships, the repair mechanism assigns the feasible activities randomly. Remaining activities not considered in any part of the sequence flow are erased as well. By applying this repair mechanism, we purely focus on feasible solutions and exploit combination patterns. Thereby, we speed up optimization and proactively exclude many misleading areas in the problem space. Limiting the problem space beforehand helps to search the remaining areas in the problem space more thoroughly and makes it more likely to determine designs with a high performances.

Table III.3-3 demonstrates the stepwise application of the repair mechanism to the first random selection of the initial population in Table III.3-2. For r_7 and r_8, the repair mechanism adds the activities a_7 and a_8 going backwards from process output since the available activities do not cover all forms of the attribute "hotel category". As a_1 and a_2 or a_3 and a_4 respectively are mutual alternatives, the repair mechanism implements exclusive splits with randomly selected decisive values. Finally, the repair algorithm proceeds with arranging activities according to the pre-defined rules and creates a feasible design.

Table III.3-3. Step by step guide for the repair mechanism

(1)	Check Process design for missing output:	$< PI, a_1, a_2, a_3, a_4, PO >$
(2)	Add activity that provides r_8:	$< PI, a_1, a_2, a_3, a_4, a_8, PO >$
(3)	Add further activity that provides r_8, as existing do not cover all attributes:	$< PI, a_1, a_2, a_3, a_4, a_7, a_8, PO >$
(4)	Add activity that provides r_6:	$< PI, a_1, a_2, a_3, a_4, a_5, a_7, a_8, PO >$
(5)	Repeat the steps for all other resources:	$< PI, a_1, a_2, a_3, a_4, a_5, a_7, a_8, PO >$
(6)	Erase activities that do not contribute to the production of the process output:	$< PI, a_1, a_2, a_3, a_4, a_5, a_7, a_8, PO >$

(7)	Arrange activities:	$< PI, AND\left(XOR(d_1(v_{1_2};=);a_1;a_2),a_5;XOR(d_1(v_{1_4};=);a_3;a_4),XOR(d_1(v_{1_5};=);a_8;a_7)\right),PO >$

III.3.5.3.3 Evaluating the fitness of created process designs

In order to evaluate the potential design candidates, we follow the paradigm of VBM. More specifically, we propose the valuation function from Bolsinger (2015). This approach has four beneficial implications. First, it reduces the multi-dimensionality of the valuation problem for process redesign projects (cf. Limam Mansar et al. 2009) to a single objective which is increasing the company's value. Second, it enables the consideration of uncertainties about future process performances. Third, it extends the optimization potential of current approaches by enabling the valuation of conditions at decision nodes and integrating them into the optimization. Fourth, the application of value-based management increases the performance of EAs and enables its application also for complex processes.

As one of the most accepted valuation functions, VBM proposes the preference functional ϕ. This function has proven to be applicable for decisions on the operational process level (Bolsinger 2015). The preference functional fulfills the central requirements of VBM which are the focus on cash flows, the consideration of the time value of money and of the risk attitude of the decision-maker (see design objective O.2). These requirements are fulfilled by considering three central variables: The expected net present value of process cash flows $\mu_{NPV} = E\left[\widetilde{CF}_{NPV}\right]$ as a measure of efficiency and effectiveness, the uncertainty of those cash flows represented by their expected variance $\sigma_{PV}^2 = Var\left[\widetilde{CF}_{NPV}\right]$ as a measure of risk and the risk aversion of the decision-maker α. It is defined as:

$$\phi(\mu_{NPV}, \sigma_{NPV}) = \mu_{NPV} - \frac{\alpha}{2} \cdot \sigma_{NPV}^2 \quad (1)$$

Whereas the risk aversion is constant across process designs, our EA calculates μ_{NPV} and σ_{NPV}^2 for each created process design according to equations (2) and (3).

$$\mu_{NPV} = -I + \sum_{t=0}^{T} \frac{n_t \cdot \mu_P}{(1+i)^t} \quad (2) \qquad \sigma_{NPV}^2 = \sum_{t=0}^{T} \frac{n_t \cdot \sigma_P^2}{(1+i)^{2t}} \quad (3)$$

μ_{NPV} is defined as the difference between the initial investment for the implementation of a new process design I and the sum of the expected cash flows generated at run time. The initial investment includes a constant amount I_{fix} for conducting process redesign and a variable amount I_{var} depending on the number of new activities established. New activities lead to cash outflows for implementation and staff training among others. Within the considered time horizon T the process runs n-times in each period $t \in T$ and generates expected periodic cash flows μ_P. The periodic cash flows are then discounted by an interest rate i to the present day. Similarly, we calculate σ_{NPV}^2 as the sum of the variances for the single process executions σ_P^2 in period t within the total planning horizon T and discount with i. General planning variables like I_{fix}, I_{var}, T, and i need to be set in advance, they do not change within an EA run and they are invariant to the process design.

In contrast, μ_P and σ_P^2 are design-specific and depend on the contained activities a_x as well as their probability of appearance p_{a_x}. Equations (4) and (5) define the calculation of the economic decision variables for a process design. While an activity's expected cash flow μ_{a_x} as well as its expected standard deviation σ_{a_x} come directly from *activity-attribute matrix*, its probability p_{a_x} originates from the *activity-process-attibute-matrix* and depends on the gateways that define the paths along which a process design can be traversed.

$$\mu_P = \sum_{d=1}^{D} \mu_{a_d} \cdot p_{a_d} \tag{4}$$

$$\sigma_P^2 = -\mu_P^2 + \sum_{d=1}^{D} \left(\sigma_{a_x}^2 + \mu_{a_x}^2\right) \cdot p_{a_d} + 2 \cdot \sum_{d=1}^{D-1} \sum_{b=d+1}^{D} \mu_{a_d} \cdot \mu_{a_d} \cdot p_{(a_d,a_b)} \tag{5}$$

In our example, applying the repair mechanism to the initial population leads to five feasible process designs (See Table III.3-4). The values of the fitness function with $I = 0, T = 5, i = 2.5\%, n = 100$, and $\alpha = 0.05$ are also shown.

Table III.3-4. Fitness values of the "repaired" initial population

Process design	$\phi(\mu_{NPV}, \sigma_{NPV})$
$< PI, AND\left(a_1, a_5; a_4, XOR\left(d_1(v_{1_5};=); a_8; a_7\right)\right), PO >$	9,984.12
$< PI, AND\left(XOR\left(d_1(v_{1_2};=); a_1; a_2\right), a_5; XOR\left(d_1(v_{1_4};=); a_3; a_4\right), XOR\left(d_1(v_{1_5};=); a_8; a_7\right)\right), PO >$	9,420.80
$< PI, AND\left(a_1, a_6; a_4, XOR\left(d_1(v_{1_5};=); a_8; a_7\right)\right), PO >$	15,606.79
$< PI, AND\left(a_1, a_5; XOR\left(d_1(v_{1_3};=); a_4; a_3\right), XOR\left(d_1(v_{1_5};=); a_8; a_7\right)\right), PO >$	14,260.88
$< PI, AND\left(a_2, a_6; a_3, XOR\left(d_1(v_{1_5};=); a_8; a_7\right)\right), PO >$	23,166.22

III.3.5.3.4 The selection mechanism

We apply two types of selection mechanisms: the elitist selection and the tournament selection. In the elitist selection, a defined number of currently best known designs gets directly copied to the next generation without undergoing recombination or mutation. Hence, we can ensure that the best process designs can traverse to the end. As our completing selection mechanism, we use tournament selection to balance exploration and exploitation. Thereby, we implement moderate selection pressure while still allowing for further fine tuning and preventing premature convergence towards local optima (De Jong 2006). In tournament selection, a specified number of designs of the current population competes with their fitness values $\phi(\mu_{NPV}, \sigma_{NPV})$ against each other. Thereby, the amount of competitors needs to be set in advance and remains constant throughout the optimization run. The higher the amount of competitors, the higher is the selection pressure and the more likely is premature convergence. In each competition, the design with the highest fitness value gets chosen as a parent for the next generation. For the travel agent process, Figure III.3-6 provides exemplary tournament selections with the winner marked in bold.

Exemplary tournament selection with number of competitors = 4
$< PI, AND\left(a_1, a_5; a_4, XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< PI, AND\left(XOR(d_1(v_{1_2};=); a_1; a_2), a_5; XOR(d_1(v_{1_4};=); a_3; a_4), XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< PI, AND\left(a_1, a_5; XOR(d_1(v_{1_3};=); a_4; a_3), XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< \mathbf{PI, AND\left(a_2, a_6; a_3, XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO} >$

Exemplary tournament selection with number of competitors = 3
$< PI, AND\left(a_1, a_5; a_4, XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< \mathbf{PI, AND\left(a_1, a_6; a_4, XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO} >$
$< PI, AND\left(a_1, a_5; XOR(d_1(v_{1_3};=); a_4; a_3), XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$

Exemplary tournament selection with number of competitors = 2
$< PI, AND\left(XOR(d_1(v_{1_2};=); a_1; a_2), a_5; XOR(d_1(v_{1_4};=); a_3; a_4), XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< \mathbf{PI, AND\left(a_2, a_6; a_3, XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO} >$

Exemplary tournament selection with number of competitors = 5
$< PI, AND\left(a_1, a_5; a_4, XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< PI, AND\left(XOR(d_1(v_{1_2};=); a_1; a_2), a_5; XOR(d_1(v_{1_4};=); a_3; a_4), XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< PI, AND\left(a_1, a_6; a_4, XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< PI, AND\left(a_1, a_5; XOR(d_1(v_{1_3};=); a_4; a_3), XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO >$
$< \mathbf{PI, AND\left(a_2, a_6; a_3, XOR(d_1(v_{1_5};=); a_8; a_7)\right), PO} >$

Figure III.3-6. Tournament selection examples

Due to a predefined recombination probability, the winning competitor is combined with a second parent from a second tournament selection into an offspring. In this case, the EA modifies the offspring additionally by the recombination and mutation mechanisms (see next section). Otherwise, the offspring is just a (probably mutated) copy of the winning competitor and not a combination of two designs. After having produced an offspring design, the parent design returns to its population and may still be a parent for further offspring. This customization enables that more than one variation of a promising design may traverse to the next generation.

III.3.5.3.5 The reproduction mechanisms

When creating new designs, our EA considers three mechanisms: copying, recombination and mutation. The first one, copying, retains promising process designs from the elitist selection but does not provide further information about the problem space. It ensures that the best solutions can traverse to the end. Recombination and mutation introduce new designs and, hence, help to explore the problem space. Whereas, recombination supports local search, mutation ensures global search within the problem space. Therefore, our application builds on selection mechanisms to seize designs with higher performance, it exploits recombination for combining promising designs in novel ways and mutation for creating new designs. Before innovating process designs in the latter two reproduction mechanisms, our algorithm re-translates parent designs into activity lists and abstracts from the structural appearances. Thereby, we can reduce the bias towards children having the same structures and conditions in their process designs as their parents. As this condensed interpretation of recombination and mutation does not ensure that the offspring represent feasible process designs, the activity lists of the new designs undergo the repair algorithm before re-translating them into process designs.

For recombination, the parents' designs randomly exchange activities resulting in two new designs following a two-point crossover. With a predetermined probability, the first parent exchanges two of its activities for one activity (see ② in Figure III.3-7). Otherwise, the parents exchange one activity for another (see ① in Figure III.3-7). As a consequence, offspring of varying sizes evolve. For mutation, each activity in the list of the offspring is exchanged with a predetermined mutation probability against a random activity from the library (see ③ in Figure III.3-7). The determination of the mutation probability is crucial. A higher mutation probability leads to a higher explorative character of the EA but makes it also more similar to random search. However, if the mutation probability is low, premature convergence is likely.

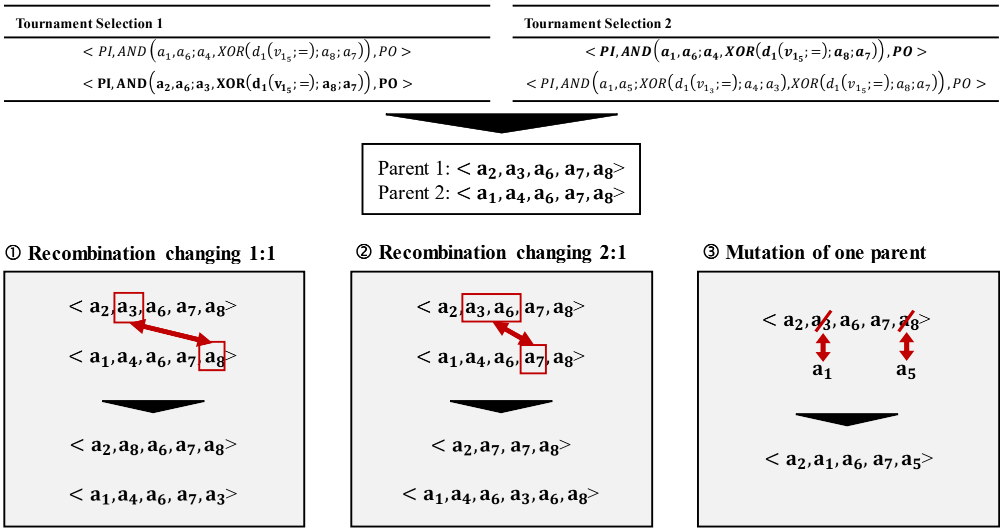


Figure III.3-7. Recombination and mutation examples

III.3.5.3.6 Summary

The selection and reproduction mechanisms lead to offspring that, in turn, represent their parents for the next generation of process designs. This cycle will continue until a termination criterion is reached. The EA run finishes either by reaching the maximal number of generations or after a specified number of generations without a change of the best known design. Then, the EA returns the best process designs.

In all, EAs allow for a wide range of parameter settings. This flexibility enables the algorithm to cope with a high number of processes. Process designers may set the parameters according to the nature of the process at hand and their goals. Our EA shows a high exploitative character when dealing with process designs of low complexity and a higher explorative character when facing complex optimization problems. Figure III.3-8 summarizes our results and the input parameters presented in this section.

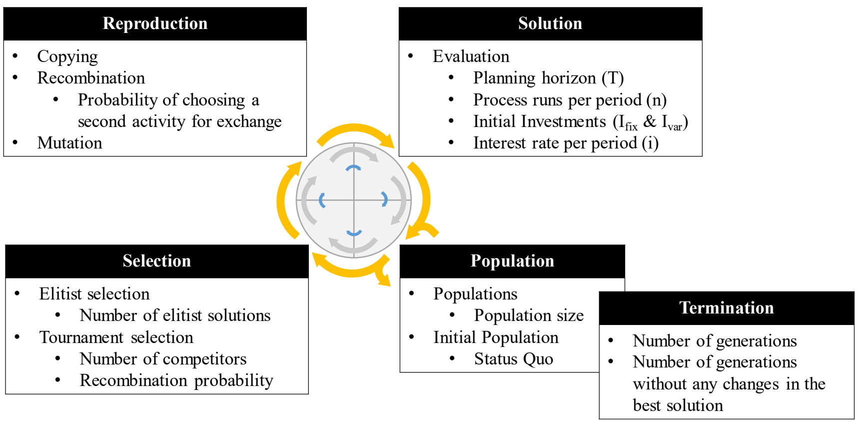


Figure III.3-8. Input parameter for EA application

III.3.6 Evaluation

III.3.6.1 Validation of the Design Specification (EVAL2)

In order to evaluate if the design specification of our computational support for process redesign suitably addresses our research question, we discuss its key features against the pre-defined design objectives obtained from justificatory knowledge. This validation corresponds to the so called feature comparison, an ex-ante and artificial evaluation method (Venable et al. 2012).

From a stand-alone perspective, our EA application addresses all design objectives. Table III.3-5 illustrates details. Nevertheless, future research may improve our application with respect to some design objectives. For example, the application only considers the focal process from a stand-alone perspective and abstracts from interdependencies to other processes within the organization. An extension to a process portfolio consideration could be realized by including interdependencies in the *activity-attribute matrix*. The valuation function could then consider correlations in the variance term (O.2). Although our application computationally implements the BPM lifecycle as the most popular redesign paradigm in practice and thereby probably achieves a high acceptance among practitioners, it still remains a data-based and computational approach. A data-driven attitude and a kind of confidence into computational applications among the target users is key. Therefore, future research should investigate how our EA can be combined with more intuitive approaches like the creative redesign process (Limam Mansar et al. 2009) to further foster organizational acceptance (O.3).

Table III.3-5. Results of feature comparison

Design Objectives		Characteristics of our CI applications
Summary		*Our algorithm supports the development of new designs that better fit restrictions of a process. It analyzes process information represented in compiled matrices, it recombines and incrementally changes activities. Finally, it prioritizes new designs with respect to their promised value contributions. Thereby, the algorithm turns the intuitive and subjective approach of "human-based" redesign initiatives to the unbiased, computational level.*
(O.1)	**Process Elements**	Our application considers with sequential, parallel and disjunctive connections the most relevant elements from BPM. With the consideration of conditions, we can identify better designs according to process or environmental characteristics. Further, our application incrementally changes processes by a stepwise recombination of activities and connections towards a clearly prioritized set of promising designs.
(O.2)	**Evolutionary Redesign**	Our algorithm is a computational implementation of the BPM lifecycle which is the most accepted redesign approach in the practical, offline world. Additionally, it deals with the most familiar design elements. The low run-time and the ability to address very complex processes further foster acceptance among practical decision-makers.
(O.3)	**Value-based Management**	Our algorithm uses a fitness function that stems from VBM and covers cash flows, the time value of money and the risk attitude of decision-makers. The long term perspective of VBM enables us to reduce the multiple dimensions of process performance to the main economic factors of cash inflows, cash outflows and cash flow risk.

III.3.6.2 Prototype Construction and Validation (EVAL3)

Aiming at validated artefact instantiations, we built and tested a simulation-based software prototype to provide a proof of concept. The basis of our prototype is MS Excel. We implemented the computational logic using VBA. Both, MS Excel and VBA, are popular in corporate decision-making making enabling our prototype for further applications in naturalistic settings. For computing purposes, we use a more application-friendly notation (e.g., $A01A$ for a_1, $D01D$ for d_1) compared to the formal presentation of the EA notation.

Using the prototype requires several steps. First, activities, resources, and conditions need to be defined. Second, relevant information about these elements need to be gathered to fill the five matrices: the *activity-attribute matrix*, the *resource-attribute matrix*, the *activity-input matrix*, the *activity-output matrix* and the *activity-process-attribute matrix*. Third, general planning variables (e.g., planning horizon, interest rate, risk aversion) and technical EA parameters (e.g., population size, number of generations, recombination probability) need to be set. All information can be easily accessed via input spreadsheets. Several output spreadsheets summarize the results of the EA run, and provide analytic functionalities. While the EA summary sheet (Figure III.3-9) only lists performance information and highlights the best designs, the evaluation sheet (Figure III.3-10) graphically presents the development of the fitness value over generations and provides further statistics about the simulated designs as well as the included activities.

		No. of Activities			Objective value			E[CF]			σ (E[CF])			average time		
Run	Generation	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min
Run0110	G01	4,70	5,00	4,00	595,16	681,97	458,52	92,18	104,00	74,00	36,71	41,69	32,42	1,90	2,33	1,50
Run0110	G02	5,00	6,00	4,00	595,59	801,98	424,47	92,52	120,00	69,81	39,09	46,16	31,88	1,86	2,00	1,33
Run0110	G03	4,90	5,00	4,00	635,90	834,14	410,22	97,80	124,00	68,00	39,67	45,06	34,11	1,96	2,60	1,33
Run0110	G04	4,70	5,00	4,00	696,75	868,58	460,58	105,55	128,00	74,30	38,44	43,76	32,77	2,08	2,67	1,33
Run0110	G05	4,60	6,00	4,00	700,42	872,74	384,93	106,08	128,80	64,00	38,68	50,35	27,28	2,25	2,67	1,33
Run0110	G06	5,00	6,00	4,00	755,96	918,19	445,46	113,49	134,80	73,20	40,57	46,03	32,57	2,22	2,67	1,00
Run0110	G07	5,20	7,00	4,00	762,46	928,74	581,92	114,66	136,00	90,40	43,28	46,64	36,30	2,15	2,67	1,37
Run0110	G08	5,40	6,00	4,00	677,21	928,74	491,42	103,36	136,00	78,51	41,31	47,81	34,90	2,11	2,67	1,48
Run0110	G09	5,40	6,00	4,00	733,48	928,74	605,40	110,88	136,00	94,00	43,24	48,62	41,12	2,29	2,67	1,67
Run0110	G10	5,10	6,00	4,00	670,01	928,74	424,47	102,40	136,00	69,81	41,04	47,30	33,76	2,05	2,67	1,50

Figure III.3-9. EA summary spreadsheet

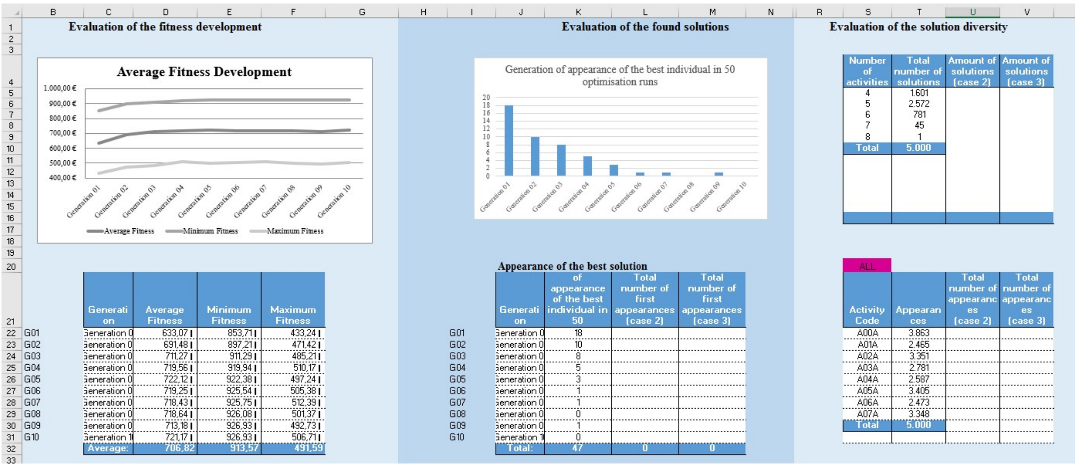


Figure III.3-10. Evaluation spreadsheet

III.3.6.2.1 Demonstration and Performance Evaluation

In order to demonstrate the applicability and usefulness of our EA application, we follow a two-step evaluation. First, we apply our EA on our running example of the travel agent process (scenario A) which is based on a modified real-life scenario from Vergidis et al. (2007) to comprehensively test the correctness of our application. Second, we apply a more complex artificial setting (scenario B) to conduct further analyses.

In order to represent the travel agent process in the five matrices of our application, we needed to translate the performance measurement in terms of quality and time to the scale of VBM. Additionally, we used a different representation of input and output and added information for routing decisions. Overall, the example contains eight activities where three activities have two alternatives each and where an exclusive split between activities a_7 and a_8 with respect to the chosen hotel category is mandatory. The process output consists of two resources created by two different activity sequences. Therefore, the scenario covers sequence, concurrency, and exclusive split while being simple enough to determine the optimal process design manually for comprehensively testing the correctness of the algorithm.

The EA found the best design, i.e., $< PI, AND\left(a_1, a_6; a_3, XOR\left(d_1\left(v_{1_5}; =\right); a_8; a_7\right)\right)$, 44 times out of 50 independent optimization runs within the first 10 generations with 10 individual designs each. Activities a_1, a_3, and a_6 are included approximately twice as often as compared to their lower performing alternatives a_2, a_4, and a_5. Activities a_7 and a_8 are part of every solution. Due to the repair mechanism, all designs include five activities. Based on these findings, we can make several conclusions about the EA's behavior: First, the EA chooses the best alternatives if two or more activities fulfill the same functions. Second, the EA integrates conditions and exclusive splits where necessary. Third, by copying evolutionary behavior and by showing a robust performance in finding optimized designs, our EA confirms its ability as a promising tool for process redesign.

To test the EA in a more complex setting, scenario B represents challenges faced by process manager in real-world BPM problems. Accounting for a multiplicity in design options, this scenario offers different ways of transferring process input into process output as schematic shown in Figure III.3-11. The EA needs to combine up to nine activities according to their input-output-relationships and choose among many alternative activities (represented by the numbers attached to the activities). The alternatives vary according to their expected cash flows and uncertainty in realizing those cash flows as well as in their fit to the process attributes. The values of the economic attributes depend on the activity's function, the activity's number of sub-steps and the usage of materials and human resources. Overall, the *activity-attribute matrix* contains 44 activities. Some alternatives integrate multiple sub-steps into an aggregated activity and exploit economies of scope (e.g., a_6 compared to the activity set a_3, a_4, and a_5). They are accordingly characterized by a higher efficiency (smaller expected cash outflows) compared to the sequence of the disaggregated alternatives. On the other hand, disaggregation makes the entire element easier to control and thus is exposed to lower risk than the aggregated activities. As a result, the EA also faces the trade-off between efficiency and risk. Other alternatives follow equal input-output-relationships regarding two process attributes (i.e., all activities summarized by a_{1X} and a_{2X}) to implement routing conditions at different stages of the process design. The matching of activities to the decisive forms of the process attributes results in exclusive splits just as overlapping activity-process-attribute-relationships. Summing all up, the EA faces a non-trivial problem of finding an optimal combination of activities, alternatives and routing decisions.

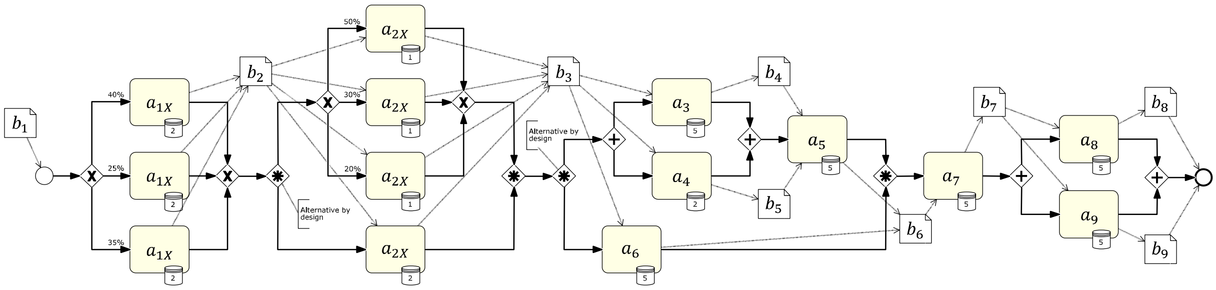
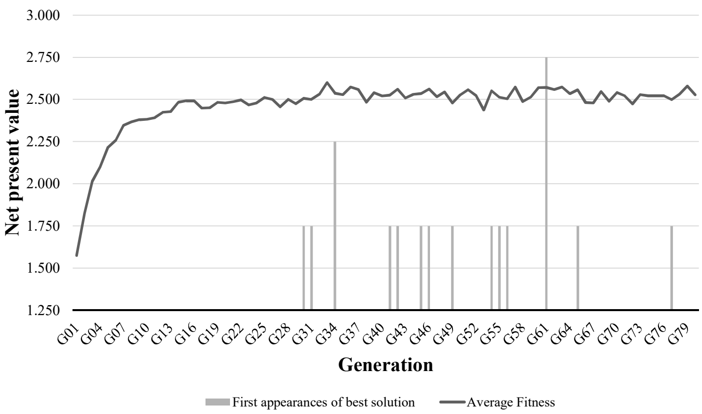


Figure III.3-11. Schematic representation of scenario B

In 25 independent runs of 80 generations with 50 individual designs each, our EA returned the identical optimal design in more than 65 percent of all cases. This design dominates all created designs as measured by the value function. Figure III.3-12 provides further insights: The average fitness of progressing generations confirms the EA's exploitative character. After a high increase of the fitness at the beginning, the EA differs slightly in the designs to approach the optimal solution. This is confirmed by the distribution of the design sizes whose wide variety also illustrates the EA's explorative character. In order to find the optimized designs, the EA produced designs of six different sizes but favored designs with 10 activities. As a result of the repair mechanism, all designs include more than eight activities. The EA found the optimal design for the first time in the 30th generation.



Design Size	Total number
6	0
7	0
8	7.255
9	20.334
10	52.419
11	3.974
12	10.356
13	5.662
14	0
15	0

Figure III.3-12. Results of scenario B

III.3.6.2.2 Discussion against Evaluation Criteria

Further validating our prototype, we also discuss its application against typical criteria for EVAL3 as compiled and assessed by Sonnenberg and vom Brocke (2012). Summarizing, this discussion indicates that the application and the prototype address all criteria. As key findings, we can state that our approach provides an effective and efficient tool for process redesign. It builds on accessible information just as well-known representations and techniques. On the other hand, it becomes evident that applicability of our customized EA for naturalistic settings requires additional developments. Detailed results are shown in Table III.3-6.

Table III.3-6. Discussion of usefulness

Criterion	Characteristics of the CI application and the software prototype
Feasibility	The prototypical implementation and the artificial cases (scenarios A and B) presented in this section illustrate that the proposed EA application is feasible for simple as well as for complex scenarios. The applied computational intelligence provides support for process redesign where other methods and mechanisms reach their limits, especially in cases of many alternative design options and required.
Ease of Use & Operationality	As we could not test our application in a real-world setting, we can only argumentatively evaluate its ease of use and operationality based on the insights we gained in the artificial environment. The EA application builds on information about activities, resources, and conditions which is already used in today's redesign initiatives. As currently conducted, the required data could be collected in automated environments by using process mining techniques. Besides, it should be possible to gather the data in non-automated environments by experts as well. The matrices for recording the data are straight forward to use as they are based on proven technologies. This argument also holds for the translation of the process designs into the computational world which we faced as greatest challenge. However, a graphical representation would assist a better understanding. As the EA should be applied repeatedly, a knowledge base should be built to institutionalize data collection routines and collect best practices.
Effectiveness, Suitability & Efficiency	The EA application can be effectively used to redesign processes. This is confirmed by the simple scenario A, which we used for plausibility checks. The fitness function as well as the repair mechanism demonstrated to ensure feasible designs. The mix of local and global search is free of subjective vagueness and uncertainty. For efficiency, we conducted performance tests with the prototype on regular work stations such as used in business environments. The EA is also highly performant in settings of various activities, resources, and conditions as well as a high amount of individual designs per generation. The optimal designs were found within a limited number of generations. In any case, the total time including recording data and applying the EA will not exceed the usual redesign time.
Fidelity with real-world phenomenon	Our EA application already considers many design elements and therefore it can handle many different constellations that may occur in naturalistic settings. In particular, our inclusion of process and case characteristics as well as the ability to integrate activities and resources with different levels of detail into our computational solution provides more possibilities and flexibility towards the process design. The analogy to the BPM lifecycle allows for a minimal invasive support for process redesign. However, our application still does not consider all design elements of processes. For example, events that may occur during process execution and the corresponding waiting times are not implemented yet.
Robustness	Based on the evaluation scenarios, the EA application provides robust solutions for process redesign. In scenario A, the EA found the optimal design in all runs. In scenario B, the EA identified the same design in most instances and shows only minor deviances in the other cases, despite the risk of local optima. However, the further development should consider additional robustness checks that also cope with estimations inaccuracies, which are inevitable in naturalistic settings.

III.3.7 Conclusion, Limitations and Outlook

This paper addressed the problem how CI can support the redesign of processes. In practice, this key task of BPM often relies on human intuition and lacks the support of computational support. As a solution to this research gap, we developed an EA that incrementally improves the status quo design promising an objective basis for further discussions in a redesign committee. Following the BPM lifecycle and integrating VBM for prioritization as practice-proven and acknowledged concepts in process decision-making, our algorithm should face a high acceptance among process decision-makers as its target users. Overall, our EA unites concepts from IS research, management sciences and BPM and thereby bundles the strengths of these diverse research areas to holistically address the interdisciplinary issue of process redesign.

The main challenge in applying CI (in general) or EAs (in particular) for process redesign is the translation of process designs into the computational world. To compile the available process information, we describe activities, resources, and their logical connections as the key elements of process designs in matrices. Moreover, our algorithm is the first EA application that allows exclusive splits considering conditions based on process attributes as a further key element of processes. As a result, our EA application can develop more realistic process designs and enable a better re-translation. In order to bridge the trade-off between keeping promising designs and searching for new solutions, the EA constructs new designs either randomly when creating the initial population or by following recombination and mutation. A repair mechanism ensures logical correctness and transforms infeasible designs, which do not produce the desired process output, into feasible designs. These feasible designs are evaluated by a valuation function from VBM and the most valuable designs form the baseline for the next generation. As a result, our algorithm can deal with complex processes in terms of a high number of activities, it provides promising design candidates in an acceptable time and it provides a clear prioritization of designs instead of a set of not-dominated designs. The entire process mimics the cognitive approach of human decision-makers but avoids the disadvantages of subjective vagueness and personal biases. It invests the strengths of CI to a real-world problem whose complexity exceeds the cognitive capacity of human beings. In other words, it constitutes a reasonable application field of human-computer interaction.

We evaluated our EA application in line with the framework proposed by Sonnenberg and vom Brocke (2012). In this paper, we reported on the results of feature comparison, prototype construction, and demonstration examples to fulfill the requirements of the evaluation activities EVAL1 to EVAL3. As the validation revealed challenges and as our approach is beset with limitations, further research is necessary. In particular, our EA will benefit from further evaluations in real-world case studies such as recommended by evaluation activity EVAL4, where the EA and the prototype are applied in naturalistic settings. Thereby, the usefulness for organizational stakeholders involved in process redesigns could be answered in detail. Besides further evaluation, the current software prototype should also be extended towards more sophisticated visualization and analysis functionality. From a conceptual perspective, the growing interdependencies of processes in todays globalized times resulting in network structures necessitate adjustments to the value function. In combination with the integration of further missing process design elements (e.g., events), additional complexity will arise from this broader interpretation imposing run time and performance problems which should be addressed by future research. Further research could also draw from the results of multi-criteria decision-making to enable a direct integration of other performance effects like time, quality and flexibility which we only considered implicitly.

Finally, our long-term research vision is to stepwise extend our current application until finally reaching the idealistic state of a fully computer-based BPM lifecycle. Looking at current developments regarding digitalization and big data, EAs will become even more powerful in the future. The exponential growth of available process information, e.g., gathered by WFMS, increases the potential of computational redesign as CI will get an increasing advantage over human intelligence. The cognitive capacity will become more and more deficient for the complexity of the redesign problem. To complete this outlook, the promising new designs identified by our EA could brought in a WFMS. The system could then automatically check its real-life performance and retransfer the gathered insights to the EA. Thereby, all relevant BPM activities from identifying, measuring, redesigning, and monitoring could benefit from CI in an automated cycle of improvement. Until then, our approach advances the computational tool-kit for process redesign by fusing CI, BPM and VBM to a complete application which addresses drawbacks from existing works.

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IV Strategic planning of redesign projects

Process improvement (e.g., an update of the process designs) is implemented via projects. Therefore, project management capabilities are necessary to select a set of improvement projects out of the variety of improvement opportunities and to bring the selected projects into a reasonable order. As a result, Chapter IV addresses an economically sound strategic planning of redesign projects. Section IV.1 *Process Improvement Roadmapping – How to Max Out Your Process* deals with the understanding about the improvement projects' effects on the process performance that, in turn, affects the organization's goals. Therefore, it introduces process characteristics as intermediate layer to reflect how work is organized and performed inspired by established industrialization strategies (i.e., automation, sourcing, flexibility, and standardization). As a result, a decision model supports process managers in the selection and scheduling of redesign projects. However, depending on the organizational contextual factors (e.g., industry), a deeper look into domain-specific characteristics and their influence on the management of improvement projects would be a worthwhile endeavor. Section IV.2 *Roadmap to flexible Service Processes – A Project Portfolio Selection and Scheduling Approach*, therefore, considers the high intrinsic need for flexibility in the most strongly growing service industry owing to the demand uncertainty and variety. As integral parts of this decision model, the resulting flexibility roadmap is based on a risky, stochastic demand to reflect different request types (i.e., runners, repeaters, and strangers) and a service provider's capacity configuration (i.e., internal, external, dedicated, and flexible capacity types). Section IV.3 *V3PM: A Decision Support Tool for Value-based Process Project Portfolio Management*, then, takes the more holistic view again, but extends the action and decision-making scope from the process level to the organizational level. It supports organizations toward decisions on the improvement of their individual processes and the development of their BPM capabilities in an integrated manner. While developing a stand-alone tool based on the prototypes of the Sections IV.1 and IV.2, Section IV.3 seeks to provide an adequate evaluation for existing design science research artefacts and represents a first step towards a full-featured version for decision support in daily business operations.

IV.1 Process Improvement Roadmapping – How to Max Out Your Process

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Abstract *Process improvement is the most value-adding activity in the BPM lifecycle. Despite the mature body of knowledge related to process improvement, there is a lack of prescriptive knowledge that takes a single-process/multi-project perspective, covers a broad range of improvement opportunities, and accounts for the characteristics of the process in focus. Against this background, we propose a decision model that helps determine an optimal process improvement roadmap in line with the principles of project portfolio selection and value-based management. A process improvement roadmap is a set of improvement projects scheduled to multiple planning periods, each of which enhances the performance of the process in focus. The decision model particularly considers process characteristics that reflect how work is performed and organized. These characteristics are inspired by established industrialization strategies, i.e., automation, sourcing, flexibility, and standardization. As for evaluation, we report on feature comparison, an expert interview, prototype construction, and a demonstration example.*

Keywords Business Process Improvement, Business Process Management, Process Decision-Making, Project Portfolio Management, Value-based Management

IV.1.1 Introduction

Process orientation is an accepted paradigm of organizational design and a source of corporate performance (Kohlbacher and Reijers 2013; Skrinjar et al. 2008). Due to constant attention from industry and academia, the business process management (BPM) community has proposed mature approaches, methods, and tools that support process design, analysis, enactment, and improvement (Harmon and Wolf 2014; van der Aalst 2013). Process improvement is the most value-creating activity within the BPM lifecycle (Dumas et al. 2013; Zellner 2011). This is why approaches to process improvement are still in high demand (van der Aalst 2013).

The body of knowledge on process improvement provides numerous process improvement approaches and related classifications. The most fundamental classification is that into continuous process improvement and business process reengineering, where the first builds on incremental and the second on radical process change (Niehaves et al. 2011; Trkman 2010; vom Brocke et al. 2011). Van der Aalst (2013) proposed a classification into model- and data-based process analysis. Data-based analysis supports process improvement while processes are executed by discovering bottlenecks, waste, or deviations. Model-based analysis, which may build on the results of data-based analysis, supports process improvement during redesign. Focusing on model-based process analysis, Vergidis et al. (2008) classify improvement approaches based on whether diagrammatic, mathematical, or execution-oriented process models are used. For instance, diagrammatic models allow for observational analysis, mathematical models for validation, verification, and optimization, and execution-oriented process models enable simulation and performance analysis.

Across all classifications, there is consensus that there is a lack of concrete guidance on how to put process improvement into practice as well as that each class of improvement approaches has individual strengths and weaknesses (van der Aalst 2013; Vergidis et al. 2008; Zellner 2011). Following the classification by Vergidis et al. (2008), process improvement approaches based on diagrammatic models are susceptible to subjective biases and cause considerable manual effort (Bolsinger et al. 2015). By nature, they take a single-process perspective (Zellner 2011). Improvement approaches based on mathematical process models have the potential to overcome the weaknesses just mentioned, but are criticized for being extremely specialized and, due to the complexity of mathematical modeling, for being restricted to very few application domains (Vergidis et al. 2008). They cover the spectrum of process improvement opportunities only fragmentarily, e.g., focusing on automation, sourcing, or flexibility or on distinct process types (Afflerbach et al. 2014; Braunwarth et al. 2010; Buhl et al. 2012). For the same reason, they mostly take a single-process and single-project perspective. Few approaches based on mathematical process models take a multi-process and/or multi-project perspective, covering a broad range of improvement opportunities. In doing so, they focus on how to prioritize processes or improvement projects as well as on how to plan process improvement and the development of an organization's BPM capability in an integrated way (Bandara et al. 2015; Darmani and Hanafizadeh 2013; Ohlson et al. 2014). As an example, Lehnert et al. (2014) propose a decision model that determines BPM roadmaps including projects that improve single processes or an organization's BPM capability. Due to the multi-process and multi-project perspective, they capture different project types and interactions among projects. Consequently, they analyze single processes on a high level of abstraction and neglect process characteristics beyond performance that reflect how work is performed and organized.

This analysis reveals that most process improvement approaches – be it approaches based on diagrammatic or on mathematical process models – take a single-process/single-project or a multi-process/multi-project perspective. The first group tends to be narrow in scope, to cover selective improvement opportunities, and to neglect the opportunity to improve a process in terms of multiple projects. The second group, in contrast, examines individual processes from a high level of abstraction, neglecting interesting characteristics beyond performance. In sum, there is a lack of prescriptive knowledge that takes a single-process/multi-project perspective on process improvement to cover a broad range of improvement opportunities and to account for process characteristics in detail. Thus, we address the following research question: *Which projects should an organization implement to improve a distinct process, particularly accounting for process characteristics that reflect how work is performed and organized?*

To answer this question, we propose and instantiate a decision model for valuating process improvement roadmaps in line with the principles of project portfolio selection (PPS) and value-based management (VBM). A process improvement roadmap is a set of process improvement projects scheduled to multiple planning periods, each of which enhances the performance of the process in focus. Since our decision model has the features of a model and a method, we adopted the design science research (DSR) paradigm (Gregor and Hevner 2013). Following the DSR reference process, we discuss the identification of and motivation for the research problem, objectives of a solution, design and development, and evaluation (Peffers et al. 2008). In the design and development phase, we used normative analytical modeling to specify the decision model (Meredith et al. 1989). With this paper, we extend our prior research on process improvement by focusing on process characteristics and by covering a broad range of improvement opportunities inspired by multiple established industrialization strategies (Lehnert et al. 2014; Linhart et al. 2015).

The paper is organized as follows: We first provide justificatory knowledge related to BPM, PPS, and VBM, while deriving design objectives for solutions to the research question (*objectives of a solution*). We then introduce our decision model (*design and development*) and report on the results of feature comparison, an expert interview, prototype construction, and a demonstration example (*evaluation*). We conclude with reviewing our key results, discussing limitations, and pointing to opportunities for future research.

IV.1.2 Theoretical Background and Design Objectives

IV.1.2.1 Process Improvement and Process Performance Measurement

BPM is "the art and science of overseeing how work is performed [...] to ensure consistent outcomes and to take advantage of improvement opportunities" (Dumas et al. 2013, p. 1). Thereby, it combines knowledge from information technology and the management sciences (van der Aalst 2013). BPM takes care of all corporate processes, which split into core, support, and management processes (Harmon 2010).

Process improvement is implemented via projects (Lehnert et al. 2014). To determine the effects of process improvement projects on process performance, performance indicators are used (Leyer et al. 2015). Process performance indicators can be grouped according to the Devil's Quadrangle, a framework that comprises time, cost, quality, and flexibility as dimensions (Reijers and Limam Mansar 2005). The Devil's Quadrangle owns its name from the fact that improving one dimension weakens at least one other, disclosing the trade-offs to be resolved during process improvement. To apply the Devil's Quadrangle, its dimensions must be operationalized via case-specific performance indicators (Dumas et al. 2013). To better understand how improvement projects affect process performance, the process characteristics provide useful information. Process characteristics are "information about the process itself [including] definition[s] of the activities, control flow[s], [...] business rules [and] resource requirements" (Sidorova et al. 2015, p. 428). Exemplary process characteristics are the number of process variants, the number of process instances per period, or the extent of automation and sourcing (Bolsinger et al. 2015; Braunwarth et al. 2010; Linhart et al. 2015).

To structure the vast amount of improvement projects, we refer to the paradigm of industrialization, which is known from the manufacturing domain and has also been transferred to the services domain (Levitt 1976). Industrialization is associated with increasing productivity and production volumes as well as with decreasing costs (Karmarkar 2014). To achieve these objectives, distinct industrialization strategies have established over time (Gileadi and Leukert 2013; Karmarkar 2004). Four industrialization strategies, i.e., standardization, automation, sourcing, and flexibility, have often been discussed in relation to process improvement. Business process standardization refers to the alignment of context-specific process variants with a master process, leading to a reduction or a unification of process variants (Beimborn et al. 2009b; Tregear 2015). The master process is an ideal-typical process variant that can be applied to all process contexts, i.e., all environments or situations in which a process is executed (Münstermann et al. 2010). Business process automation considers the internal handling of processes, focusing on the control flow or the tasks of a process (Ouyang et al. 2015; Sidorova et al. 2015; Ter Hofstede et al. 2010). The control flow can be automated by workflow management systems, i.e., software systems "which [pass] information from one participant to another" (Dumas et al. 2013, p. 298). Tasks can be automated via traditional application systems or services from service-oriented architectures (Cummins 2015). If processes or tasks are no longer handled internally, business process outsourcing or business process activity outsourcing come into place (Braunwarth 2010; Dorsch and Häckel 2014). Outsourcing is "the delegation of one or more entire business processes to third party providers, including the software and hardware that support those processes" (Wüllenweber and Weitzel 2007, p. 2). Accessing specialized process expertise in order to focus on one's core competencies are common arguments in favor of outsourcing (Davenport 2005). Finally, business process flexibility combines volume and functional flexibility, allowing processes to cope with risky demand and to create different as well as unplanned outputs (Afflerbach et al. 2014; Goyal and Netessine 2011). Volume flexibility can be addressed by demand-side measures, e.g., reservation systems or dynamic pricing (Jerath et al. 2010), or by supply-side measures such as customer integration, outsourcing, automation, or cross-training (Fitzsimmons and Fitzsimmons 2013). As for functional flexibility, strategies like flexibility-by-design, flexibility-by-deviation, flexibility-by-underspecification, flexibility-by-by-change can be leveraged, including recent advances such as declarative process design (Haisjackl et al. 2014).

Although the industrialization strategies were largely treated separately, some researchers investigated the relations among them. Standardization can be seen as a prerequisite for outsourcing (Ramakurnar and Cooper 2004). The effects of standardization on process performance are also known to be reinforced by the IT intensity of a process, which again is linked to automation (Beimborn et al. 2009a). The relationship between standardization and flexibility is ambiguous, i.e., there is a trade-off between loosing flexibility and realizing performance effects by standardization (Wimble et al. 2010). Moreover, there is a link between flexibility and sourcing, as volume flexibility can be achieved by using external capacity (Linhart et al. 2015). Even an increase in functional flexibility can be obtained by sourcing, as sourcing enables an appropriate use of internal resources (Yang et al. 2007). Finally, if a process is subject to automation and outsourcing, the sequence in which both strategies are implemented is crucial (Buhl et al. 2012). Against this backdrop, we specify the following design objective:

(O.1) *Process improvement and performance measurement*: Process performance must be conceptualized in a multi-dimensional manner. To better estimate the performance effects of improvement projects, performance indicators should be complemented by specific process characteristics.

IV.1.2.2 Project Portfolio Selection

There is a mature body of knowledge on PPS, including quantitative and qualitative approaches (Carazo et al. 2010; Frey and Buxmann 2012; Perez and Gomez 2014). PPS is the activity "involved in selecting a portfolio, from available project proposals [...] that meets the organization's stated objectives in a desirable manner without exceeding available resources or violating other constraints" (Archer and Ghasemzadeh 1999, p. 208). The PPS process comprises five stages: pre-screening, individual project analysis, screening, optimal portfolio selection, and portfolio adjustment (Archer and Ghasemzadeh 1999). In the pre-screening stage, projects are checked for strategic fit and whether they are mandatory. During individual project analysis and screening, all projects are evaluated individually and eliminated in case they violate critical thresholds of relevant performance indicators. The optimal portfolio selection stage establishes the project portfolio that best meets the performance indicators, considering interactions among projects (e.g., mutual exclusion, predecessor/successor) and case-specific constraints (e.g., latest finishing, restricted budgets) (Liu and Wang 2011; Müller et al. 2015). Finally, decision makers may adjust the optimal project portfolio.

Considering interactions among projects is a challenging but necessary requirement for PPS decisions (Lee and Kim 2001). As for IS/IT projects, multiple interaction types must be considered, i.e., inter- vs. intra-temporal, deterministic vs. stochastic, and scheduling vs. no scheduling interactions (Kundisch and Meier 2011). Intra-temporal interactions affect single portfolios, whereas inter-temporal interactions influence decision-making based on potential follow-up projects (Gear and Cowie 1980). Inter-temporal interactions depend on the sequence in which projects are implemented (Bardhan et al. 2004). Scheduling interactions occur if projects may start at different points. We specify the following design objective:

(O.2) *Project portfolio selection*: Determining the optimal process improvement roadmap requires that only projects be considered that both affect the process in focus and align with the organization's strategy. The optimal process improvement roadmap must be determined according to the performance effects of the pre-selected projects, interactions among these projects, and further case-specific constraints.

IV.1.2.3 Value-based Management

Building on the seminal work of Copeland et al. (1990), Rappaport (1986), and Stewart (1991), VBM considers maximizing the long-term company value, based on discounted cash flows, as the primary objective of all business activities. Companies must be able to quantify not only their value on an aggregate level, but also the value contribution of individual activities and decisions, including process decisions. To comply with the principles of VBM, decisions must be based on cash flows, consider risks, and incorporate the time value of money (Bolsinger 2015). Due to its long-term orientation, VBM complies with the stakeholder value approach and other approaches to multi-perspective corporate management (Danielson et al. 2008). Functions to be used for determining the value contribution depend on the decision situation and the decision makers' risk attitude (Berger 2010). Under conditions of certainty, decisions can be made based on the NPV of future process cash flows. In case of risk with risk-neutral decision makers, decisions can be made based on the expected NPV. In case of risk-averse decision makers, decisions can be made using the

NPV's risk-adjusted expected value or a risk-adjusted interest rate. Against this backdrop, this leads to the following design objective:

(O.3) *Value-based management*: The optimal process improvement roadmap is that with the highest value contribution. Determining the value contribution of process improvement roadmaps requires accounting for cash flow effects, the decision makers' risk attitude, and the time value of money.

IV.1.3 Artefact Description

In line with the principles of PPS and VBM, the decision model aims at identifying the process improvement roadmap with the highest value contribution. A process improvement roadmap is a portfolio of scheduled improvement projects, each of which enhances the performance of the process in focus. Improvement projects can affect process performance directly or indirectly via process characteristics. To transform the effects of improvement projects stepwise into the value contribution of a process improvement roadmap, we structure the decision model into four connected layers, i.e., the project layer, process characteristics layer, process performance layer, and economic valuation layer. Figure IV.1-1 provides a high-level, single-period overview of the decision model's structure and core components, which are presented in detail throughout this section. The project layer covers process improvement projects and their effects. As one of the decision model's main contributions, the process characteristics layer reflects how work is performed and organized inspired by established industrialization strategies. The process performance layer captures the outcome of the process via non-monetary performance indicators. Finally, the economic valuation layer considers all monetary and monetized performance indicators and integrates these indicators into the periodic cash flow, which in turn is an essential input for the value contribution of a process improvement roadmap. When we present the decision model below, we first elaborate on the economic valuation layer to make the general setting and the objective function clear. After that, we introduce the process performance and the process characteristics layer. We provide a discussion of the decision model's assumptions in the evaluation section. An overview of all mathematical variables is included in the Appendix.

IV.1.3.1 *Economic Valuation Layer and General Setting*

The decision model considers a single mature process within a distinct organization, multiple projects, and a multi-period planning horizon. In order to improve the process, the organization has pre-selected process improvement projects and checked these projects for appropriate strategic fit. In line with our focus on how work is performed and organized, the decision model only considers supply-side measures as improvement projects. Taking a single-process perspective, the decision model allows for implementing one project per period. However, projects can take multiple periods. If more projects are to be implemented, they must be scheduled to the periods of the planning horizon and compiled into process improvement roadmaps. When compiling roadmaps, the decision model must account for interactions among the projects and case-specific constraints. Exemplary interactions and constraints are inter-/intra-temporal interactions among projects (e.g., a project must be implemented before another) as well as project-specific (e.g., earliest beginning), process-specific (e.g., critical boundaries for performance indicators), and period-specific constraints (e.g., available budget) (Liu and Wang 2011; Müller et al. 2015; Perez and Gomez 2014).

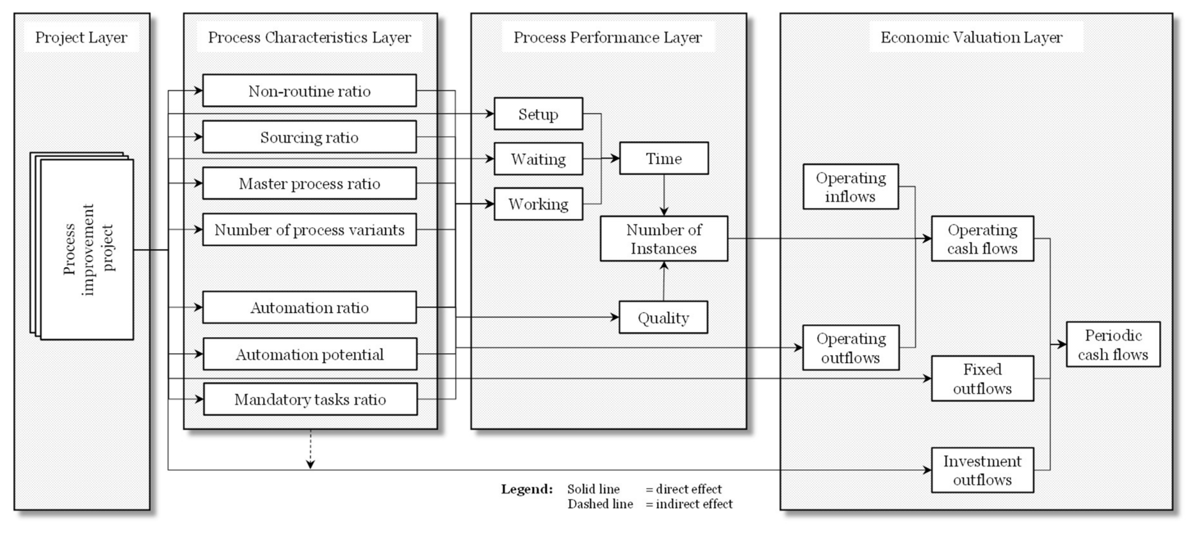

Figure IV.1-1. High-level structure and components of the decision model (single-period view)

To determine the value contribution of a distinct process improvement roadmap r in line with the principles of VBM, we use the expected NPV as the sum of all discounted periodic process cash flows (Bolsinger 2015). To do so, we take a planning horizon Y and a risk-adjusted discount rate z as input. For each period y of the planning horizon, the periodic cash flows splits into investment outflows I_y, fixed outflows f_y, and operating cash flows. Investment outflows are for implementing projects. If the implementation takes more periods, the outflows are split linearly. Fixed outflows capture outflows that accrue independently from the number of instances, e.g., for operating a workflow management system. The operating cash flows are driven by the expected number of instances D_y and by the operating inflows p and outflows v_y. The number of instances reflects the internal and external demand for the process in a distinct period. The operating inflows capture the external sales price or internal transfer price of the process output. While the investment outflows and the fixed outflows are due at the beginning of each period, the operating cash flows are due at the end of each period (Lehnert et al. 2014). This leads to the following objective function:

$$r^* = \underset{r \in R}{\operatorname{argmax}} NPV_r = \underset{r \in R}{\operatorname{argmax}} \sum_{y=0}^{Y} \left[-\frac{I_y + f_y}{(1+z)^y} + \frac{D_y \cdot (p - v_y)}{(1+z)^{y+1}} \right] \tag{1}$$

IV.1.3.2 Process Performance Layer

The decision model adopts a multi-dimensional conceptualization of process performance. In line with the Devil's Quadrangle, it focuses on the performance dimensions time, quality, costs, and flexibility (Dumas et al. 2013). While costs have already been covered in the economic valuation layer in terms of inflows and outflows, the process performance layer focuses on time and quality. Flexibility is tackled implicitly because the extent to which a process is flexible can be expressed by different components of time (Ray and Jewkes 2004). In line with our focus on supply-side measures, the decision model considers the price for executing a process instance as given and constant throughout the planning horizon. Thus, the number of instances generally depends on time and quality. If the process in focus is a business process, customers make their purchase decisions based on the time and quality observed in the previous period (Linhart et al. 2015). Depending on the process at hand, it may also be the case that the number of instances is driven by either performance dimension. In the case of support processes, the number of instances may even be invariant regarding the time and quality performance. We assume:

A1: The expected number of instances D_y in a period y can be forecast using the total processing time t_{y-1}^{total} and the total quality q_{y-1}^{total} of the previous period.

The total processing time splits into waiting time $t_{\text{wait},y}$, setup time $t_{\text{setup},y}$, and working time $t_{\text{work},y}$ (Dumas et al. 2013). Waiting time includes queueing and other waiting time. Queueing time refers to the time an instance waits before the first activity starts. As the decision model abstracts from capacity and resource constraints, instances start immediately. Thus, the waiting time expresses the time spent between two successive tasks during the execution of a single instance. The setup time refers to the time where resources (e.g., machines, devices, and employees) are prepared for executing a specific instance (Cheng and Podolsky 1996). The working time is the time where work is performed (Curry and Feldmann 2011). Unless indicated differently, the decision model refers to average time values.

Within the Devil's Quadrangle, quality can be viewed internally and externally. Internal quality refers to the error-proneness of executing process instances, typically measured in terms of error rates or availability. In contrast, external quality draws from the concept of perceived quality and is typically measured in terms of customer satisfaction (Johnston et al. 2012; Parasuraman et al. 1985). With the evaluation of the process and its output not being part of the model, we only account for the quality of internally q_y^{int} and externally handled instances q_y^{ext} (see process characteristics layer). As quality is capped (e.g., error rate cannot exceed 100%), the decision model also uses an upper quality boundary $q^{\max}$ (Dumas et al. 2013).

IV.1.3.3 Process Characteristics Layer

While time, quality, and cost take an ex-post perspective on performance, the process characteristics, which indicate how work is performed and organized, take an ex-ante and ex-nunc perspective. Thus, they help estimate time, quality, and cost more precisely. As highlighted below, the process characteristics used in the decision model are inspired by the industrialization strategies automation, flexibility, standardization, and sourcing. It also becomes clear that these strategies should not be analyzed separately. For a better understanding, we illustrate in Figure IV.1-2 how the number of process instances D_y can be decomposed based on process characteristics from the left to the right.

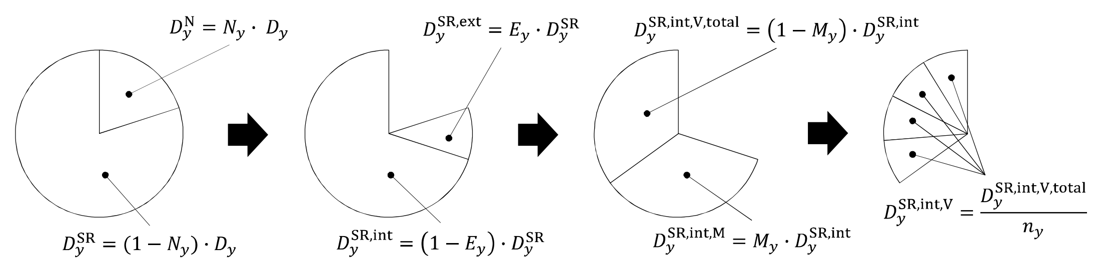

Figure IV.1-2. Decomposition of the number of process instances based on process characteristics

From a standardization and flexibility perspective, process instances split into three instance types, namely standard, routine, and non-routine instances (Lillrank 2003). Standard instances have well-defined inputs and outputs, whereas routine instances are composed of standard activities. As both instance types can be performed similarly, the decision model treats them as standard/routine instances (SR) (Neuhuber et al. 2013). Non-routine instances (N) are instances whose input and output variety cannot be entirely captured at design time. Thus, they require a complex handling and functional flexibility (e.g., extensive preparatory activities, additional tasks and resources, configurable IT services, and flexible process-aware information systems). Usually, the non-routine ratio (N_y) is much smaller than the ratio of standard/routine instances (Linhart et al. 2015). Against this backdrop, we can derive the number of standard/routine and non-routine instances as shown in Figure IV.1-2. The relationship between non-routine and standard/routine instances is expressed in terms of the mandatory tasks ratio $\alpha_y \in]0;1]$ of standard/routine instances. Thereby, α_y is a one-sided indicator taking a standard/routine perspective, as the amount of additional and potentially instance-specific tasks in non-routine instances cannot be foreseen ex-ante.

As for the sourcing perspective, the sourcing ratio (E_y) separates internally (int) executed from externally (ext) executed standard/routine instances (Dorsch and Häckel 2014). Non-routine instances are executed internally due to their high complexity. When outsourcing standard/routine instances, the organization can choose between non-scalable and scalable models of external capacity supply, a decision that affects how strongly fixed outflows and operating outflows depend on the sourcing strategy (Aksin et al. 2008). From a standardization perspective, the internally executed standard/routine instances can be allocated either to a context-agnostic master process or to one of n_y context-specific process variants according to the master process ratio (M_y). To capture differences between the master process and the process variants, we rely on dimension-specific multipliers (i.e., γ_y^{time}, γ_y^{qual}, γ_y^{cash}). These multipliers can be understood as a discount for the master process or a surcharge for the process variants based on the idea that the master process typically outperforms the process variants (Münstermann et al. 2010). We assume:

A2: Each process instance is executed either internally or externally. All relevant performance indicators for externally executed process instances are specified via service level agreements (SLA). The process instances not allocated to master process are equally distributed to context-specific process variants.

Internally executed instances must not only be differentiated according to whether they are allocated to the master process or process variants, but also according to the extent by which they are executed automated or manually. As all internally executed instances, not only standard/routine instances, can be automated, automation is orthogonal with respect to instance types. This is why automation is not included in Figure IV.1-2. In general, process instances are executed partly manually and automated according to the automation ratio A_y and the automation potential φ_y^{auto} (Figure IV.1-3). Note that the automation ratio is defined relatively to the automation potential, indicating which fraction of the potential is tapped. Moreover, the automation ratio and potential are restricted to the task perspective of process automation. We assume:

A3: The organization is able to estimate reference points for the performance dimensions time, quality, and costs for the scenario where the automation potential is fully tapped (i.e., all automatable activities have been automated) as well as for the scenario where all tasks are performed manually.

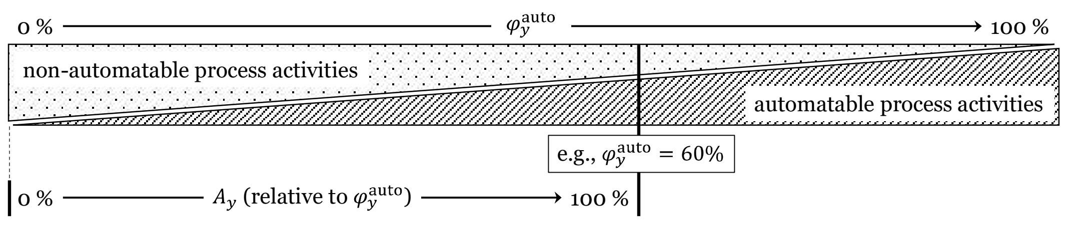

Figure IV.1-3. Relationship between automation ratio and automation potential

Having specified process characteristics based on industrialization strategies, we can now model the link between the process characteristics layer and the process performance layer mathematically. As for the time dimension, we distinguish different components for standard/routine and non-routine instances. The processing time of standard/routine instances consists of waiting time and working time. The setup time only applies to non-routine instances. As non-routine instances are much more complex, they also require additional working time $\Delta t_{\text{work},y}^{\text{N}}$. For the same reason, additional activities cannot be automated. Thus, the automation ratio and potential result in a mixed calculation for the working time of standard/routine instances. In line with the mandatory tasks ratio, the working time of standard/routine instances influences the working time of non-routine processes. The waiting time of non-routine instances, in contrast, does not depend on the mandatory tasks ratio. This is why we consider a specific waiting time for non-routine instances. Thus, the average total processing time in a distinct period is calculated as follows:

$$t_y^{\text{total}} = t_y^{\text{SR}} \cdot (1 - N_y) + t_y^{\text{N}} \cdot N_y \quad (2)$$

$$t_y^{\text{N}} = t_{\text{setup},y}^{\text{N}} + t_{\text{wait},y}^{\text{N}} + t_{\text{work},y}^{\text{N}} \quad (3)$$

$$t_{\text{work},y}^{\text{N}} = \alpha_y \cdot t_{\text{work},y}^{\text{SR,int}} + \Delta t_{\text{work},y}^{\text{N}} \quad (4)$$

$$t_y^{\text{SR}} = t_y^{\text{SR,int}} \cdot (1 - E_y) + t_y^{\text{SR,ext}} \cdot E_y \quad (5)$$

$$t_y^{\text{SR,int}} = t_{\text{wait},y}^{\text{SR,int}} + t_{\text{work},y}^{\text{SR,int}} \quad (6)$$

$$t_{\text{work},y}^{\text{SR,int}} = t_{\text{work},y}^{\text{SR,int,M}} \cdot \left(M_y + (1 - M_y) \cdot \gamma_y^{\text{time}}\right) \quad (7)$$

$$t_{\text{work},y}^{\text{SR,int,M}} = \frac{A_y}{\varphi_y^{\text{auto}}} \cdot t_{\text{work},y}^{\text{SR,int,M,auto}} + (1 - A_y) \cdot t_{\text{work},y}^{\text{SR,int,M,man}} \quad (8)$$

The quality dimension cannot be discussed as detailed as time because quality must be operationalized first. Hence, there is no relationship between the quality of non-routine and standard/routine instances. That is, the quality of non-routine instances and standard/routine instances must be assessed separately. Moreover, the quality of externally executed standard/routine instances must be extracted from the SLA. The quality of internally executed standard/routine instances shows a structural analogy with the time dimension concerning the execution of activities, i.e., it is determined based on the automation ratio and potential. This leads to the average total quality shown below.

$$q_y^{\text{total}} = q_y^{\text{SR}} \cdot (1 - N_y) + q_y^{\text{N}} \cdot N_y \quad (9)$$

$$q_y^{\text{SR}} = q_y^{\text{SR,int}} \cdot (1 - E_y) + q_y^{\text{SR,ext}} \cdot E_y \quad (10)$$

$$q_y^{\text{SR,int}} = q_y^{\text{SR,int,M}} \cdot \left(M_y + (1 - M_y) \cdot \gamma_y^{\text{qual}}\right) \quad (11)$$

$$q_y^{\text{SR,int,M}} = \frac{A_y}{\varphi_y^{\text{auto}}} \cdot q_y^{\text{SR,int,M,auto}} + (1 - A_y) \cdot q_y^{\text{SR,int,M,man}} \quad (12)$$

While the performance indicators for time and quality are aggregated to total average values before serving as input for determining the number of process instances, the economic dimension can be distinguished by instance types. The operating outflows for the master process and the process variants are, analogously to time and quality, influenced by the automation ratio and potential. To appropriately capture the effects of standardization and automation, we also incorporate experience curve effects on manual work (Henderson 1973). The more instances are handled by a distinct process variant including the master process, the more that variant benefits from experience effects. The reason is that the operating outflows are known to drop by a constant percentage each time the cumulated number of instances doubles. This effect is expressed by a power law function with a constant elasticity a for both the master and the other variants. We assume:

A4: The operating outflows for manual work are constant within a period. The process is such mature that the experience curve is at its flat end. If the operating outflows are affected by improvement projects, we receive several experience curves for the process in focus as the calculation base changes.

$$v_y^{\mathrm{SR,int,M}} = \frac{A_y}{\varphi_y^{\mathrm{auto}}} \cdot v_y^{\mathrm{SR,int,M,auto}} + \left(1 - A_y\right) \cdot v_y^{\mathrm{SR,int,M,man}} \tag{13}$$

$$v_y^{\mathrm{SR,int,M,man}} = v_0^{\mathrm{SR,int,M,man}} \cdot \left(\sum_{j=0}^{y-1} D_j^{\mathrm{SR,int,M}}\right)^{-a} \tag{14}$$

$$v_y^{\mathrm{SR,int,V}} = \left(\frac{A_y}{\varphi_y^{\mathrm{auto}}} \cdot v_y^{\mathrm{SR,int,M,auto}} + \left(1 - A_y\right) \cdot v_y^{\mathrm{SR,int,V,man}}\right) \cdot \gamma_y^{\mathrm{cash}} \tag{15}$$

$$v_y^{\mathrm{SR,int,V,man}} = v_0^{\mathrm{SR,int,M,man}} \cdot \left(\sum_{j=0}^{y-1} D_j^{\mathrm{SR,int,V}}\right)^{-a} \tag{16}$$

The operating outflows for non-routine instances are based on the operating outflows for the master process and the other variants, linked by the mandatory tasks ratio. As the position of mandatory tasks within the process and their amount can slightly change across the master process and the process variants, a mixed calculation applies best for non-routine instances. Further, additional operating outflows are needed. The fixed outflows in a distinct period split into fixed outflows for externally executed instances, outflows for internally executed standard/routine and for non-routine instances. Fixed outflows for standard/routine instances are needed to perform the standard tasks (e.g., wages, resource consumption, and IT support). Fixed outflows for non-routine instances accrue for performing extraordinary tasks (e.g., preparatory tasks, additional tasks and resources, and configurable IT services). Fixed outflows for external instances can relate to the sourcing process (e.g., contract negotiation) or to capacity (e.g., non-scalable capacity).

$$v_y^{\mathrm{N}} = \left(M_y \cdot v_y^{\mathrm{SR,int,M}} + \left(1 - M_y\right) \cdot v_y^{\mathrm{SR,int,V}}\right) \cdot \alpha_y + \Delta v_y^{\mathrm{N}} \tag{17}$$

$$f_y = f_y^{\mathrm{SR,int}} + f_y^{\mathrm{SR,ext}} + f_y^{\mathrm{N}} \tag{18}$$

Finally, the decision model accounts for sales or transfer prices for standard/routine instances p^{SR} and for non-routine instances p^{N} because customers may be willing to pay a premium for non-standard instances.

IV.1.3.4 Project Layer

Improvement projects can affect process performance directly or indirectly via process characteristics. Depending on the project, effects can be relative or absolute as well as positive, negative, or neutral. For example, the waiting time can be increased by 50%, decreased by 20 minutes, or left unchanged. Relative effects must be linked multiplicatively from one period to another, absolute effects must be linked additively (Lehnert et al. 2014). It must be considered that the ratios used in the decision model, e.g., the automation or sourcing ratio, are limited to the interval $[0; 1]$. Depending on the case, the upper boundaries can also be smaller, e.g., if the organization strategically decides that at most 75 % of instances should be outsourced.

The most complex effects are those caused by standardization. The reason is that standardization affects the number of process variants, which in turn influences the master process ratio, the sourcing ratio, and the non-routine ratio. The decision model allows for two scenarios. The first scenario is that the number of process variants is reduced to exploit experience curve effects and to leverage the performance surplus of the master process. This scenario requires shifting standard/routine instances that were so far allocated to context-specific variants to the master process. As a reduction of process variants may reduce the output variety of the process, the organization may lose its ability to assign an instance to the process variant that fits best (Ludwig et al. 2011). Therefore, only a distinct fraction λ of the shifted instances is allocated to the master process, whereas the other instances become non-routine instances (Figure IV.1-4).

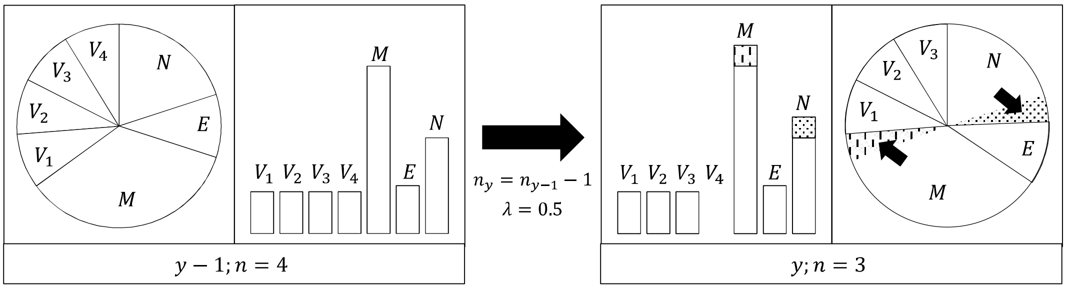

Figure IV.1-4. Shifting standard/routine instances to the master process and non-routine instances

Assuming that there are no other projects effects, the master process ratio, the sourcing ratio, and the non-routine ratio can be specified as follows for the first scenario of standardization:

$$M_y = \frac{M_{y-1} + \frac{1}{n_{y-1}} \cdot (n_{y-1} - n_y) \cdot (1 - M_{y-1}) \cdot \lambda}{1 - \frac{1}{n_{y-1}} \cdot (n_{y-1} - n_y) \cdot (1 - M_{y-1}) \cdot \lambda} \tag{19}$$

$$E_y = \frac{E_{y-1}}{1 - \frac{1}{n_{y-1}} \cdot (n_{y-1} - n_y) \cdot (1 - M_{y-1}) \cdot \lambda} \tag{20}$$

$$N_y = N_{y-1} + \frac{1}{n_{y-1}} \cdot (n_{y-1} - n_y) \cdot (1 - M_{y-1}) \cdot \lambda \cdot (1 - E_{y-1}) \cdot (1 - N_{y-1}) \tag{21}$$

The second scenario is that standardization leads to additional variants. If some non-routine instances can be executed similarly, the organization can design a new process variant. As all process variants are treated equally with respect to the number of allocated instances, the shift results from the number of instances per variant as valid in the previous period. In this case, no special ratio is needed. For this second scenario, the master process ratio, the sourcing ratio, and the non-routine ratio can be calculated as follows.

$$M_y = \frac{M_{y-1} \cdot (1 - E_{y-1}) \cdot (1 - E_{y-1})}{(1 - E_y) \cdot (1 - N_y)} \tag{22}$$

$$E_y = \frac{E_{y-1} \cdot (1 - N_{y-1})}{1 - N_y} \tag{23}$$

$$N_y = N_{y-1} - \frac{1}{n_{y-1}} \cdot (n_{y-1} - n_y) \cdot (1 - M_{y-1}) \cdot (1 - E_{y-1}) \cdot (1 - N_{y-1}) \tag{24}$$

Finally, each process improvement project causes investment outflows. These investment outflows may not only depend on the size and complexity of the project itself, but also be driven by the values of some process characteristics that hold in the period for which the project is scheduled, depending on the relations among the industrialization strategies outlined in the theoretical background. For example, automating a process or outsourcing some instances may depend on the number of process variants. Moreover, standardizing the process may depend on the automation ratio. Modelling the investment outflows as also driven by process characteristics caters for intertemporal interactions among projects, as the process characteristics depend on which projects from the improvement roadmap have been implemented earlier.

IV.1.4 Evaluation

IV.1.4.1 Evaluation Strategy

To evaluate the decision model, we followed the evaluation framework proposed by Sonnenberg and vom Brocke (2012). The framework comprises the four activities EVAL1 to EVAL4, which refer to ex-ante and ex-post as well as to artificial and naturalistic evaluation methods (Venable et al. 2012). With EVAL1 aiming at justified problem statements and design objectives, we derived the need for advancing extant prescriptive knowledge on process improvement as a meaningful DSR problem via a literature review. We also derived design objectives from justificatory knowledge related to BPM, PPS, and VBM to assess whether an artefact helps solve the research problem. EVAL2 strives for validated design specifications. We therefore discussed the decision model against the design objectives in terms of a feature comparison, an ex-ante and artificial evaluation method. Complementarily, we conducted an interview with four industry experts, an ex-ante and naturalistic evaluation method, to gather preliminary insights into whether organizational stakeholders consider the decision model's design specification as valid. We present the results of feature comparison and the expert interview jointly with a particular focus on discussing the decision model's assumptions. As for EVAL3, aiming at validated artefact instantiations, we built and tested a software prototype. A scenario analysis in an artificial setting confirmed applicability. To make the prototype demonstration more realistic, we used anonymized data from our discussions with industry experts. So far, we have not yet conducted activity EVAL4 involving real tasks, real systems, and real people, which would corroborate the decision model's applicability and usefulness in naturalistic settings. This is planned for future research.

IV.1.4.2 Feature Comparison, Expert Interview, and Discussion (EVAL2)

We discuss the results of feature comparison and the expert interview along the design objectives previously derived from justificatory knowledge. We pay particular attention to assumptions as the assumptions must be considered when interpreting the decision model's recommendations. The decision model addresses all design objectives. The interviewed experts agreed with the decision model's idea and design specification. However, there are also weaknesses and areas for future research.

(O.1) Process improvement and performance measurement

The decision model focuses on process improvement projects, i.e., projects that improve the performance of a single process. To assess the effects of such projects, we adopt a multi-dimensional conceptualization of process performance based on the Devil's Quadrangle. Each performance dimension is operationalized via performance indicators (e.g., time via working, setup, and waiting time). Process improvement projects affect process performance directly or indirectly via process characteristics. The characteristics used in the decision model are inspired by established industrialization strategies such as automation (e.g., automation ratio and automation potential), standardization (e.g., number of process variants and non-routine ratio), flexibility (e.g., setup time), and sourcing (e.g., sourcing ratio). Interactions among the industrialization strategies are covered via the investment outflows of process improvement projects, a means also used to incorporate interactions among projects. Interactions among projects also covered via multiplicative and additive effects on performance indicators, which are cascaded over time. The industry experts supported the structuration into multiple layers as well as the idea of incorporating process characteristics into process decision-making. The experts agreed with the included industrialization strategies, process characteristics, and performance indicators. They also indicated that, in their domain, risk and flexibility-to-change should be considered. We agree that risk can be treated as an outflow component, while flexibility-to-change can be modelled as a variable that moderates the effects of improvement projects or their investment outflows.

As for the decision model's assumption, we assumed that the expected number of periodic instances can be forecast using the total processing time and the total quality of the previous period (A1). Instead, we could have used other approaches from time-series analysis and forecasting literature, e.g., moving average with exponential smoothing. If only the previous period is used, the demand is comparatively volatile. However, the advantage is that effects of process improvement projects can be analyzed unambiguously as they are only counted once. In addition, we assume each process instance to be executed exclusively internally or externally and all relevant performance indicators for externally handled process instances to be specified in SLAs with third party providers (A2). Relaxing this assumption would imply distinguishing between sub-processes as well as to analyze which sub-processes are outsourced and how strongly the sub-processes influence the performance indicators. It would also be necessary to allocate project effects to sub-processes and consider effects of hand-over complexity. Since this alternative would extremely increase the calculation complexity and the data collection effort associated with the decision mode, we decided to work with exclusively internally or externally handled instances. Using the contractual limits specified in SLAs complies with the idea of risk-averse decision-making as third party providers are likely to deliver better performance over time than specified in the SLA. Otherwise, they would be replaced. As an alternative, actual performance values can be retrieved from regular reports, which however in turn would imply higher data collection effort. Next, we assumed process instances that are not handled via the master process to be equally distributed to process variants (A2). We made this assumption to reduce complexity. Otherwise, we had to capture topics such as arrival rates, waiting queues, and time-variant distributions of process instances to variants. This, however, would not fit the decision model's purpose as it does not aim at predicting the value contribution of one process improvement roadmap best possible, but at providing a framework for consistently comparing process improvement roadmaps in terms of the value contribution. However, the key effect of process standardization, i.e., stronger experience curve effects due to a stronger concentration of the periodic number of process instances, is covered sufficiently despite this assumption. Finally, we assumed the organization to be able to estimate reference points for the performance indicators related to time, quality, and outflows for the scenarios where the automation potential is fully tapped and where all task are performed manually (A3). This assumption is not a simplification. Rather, it allows for considering not only the automation level, but for differentiating between project effects on the automation ratio and the automation potential, which may occur independently.

(O.2) *Project portfolio selection*

The decision model takes multiple projects as input. We assumed that, in the prescreening stage of the PPS process, all projects have been checked for strategic fit and that, in the individual project analysis stage, all project effects were determined as single values. The decision model also accounts for selected constraints (e.g., predecessor/successor, restricted budgets) and considers deterministic, scheduling, intra-, and inter-temporal interactions. In order to be able to incorporate process characteristics in great detail, the decision model takes a single-process perspective. Due to its focus on process improvement, the decision model neglects projects that develop BPM as an organizational capability. We assumed that all project effects are deterministic and remain constant over time. In real-world cases, project effects can vary depending on the period of implementation and also be of stochastic nature. As the decision model includes many parameters whose values must be estimated by experts, we decided to abstract from time-variant and stochastic project effects. According to our industry experiences, this is reasonable as experts are not able to estimate such a high number of parameters depending on time. With many stochastic and interacting parameters, it would be extremely difficult to interpret the recommendations provided by the decision model. To account for uncertainty and estimation inaccuracies, we recommend conducting scenario and sensitivity analyses.

(O.3) *Value-based management*

The decision model ranks process improvement roadmaps according to their value contribution, measured as the roadmaps' expected NPV based on a risk-adjusted interest rate. The NPV reflects all monetary and monetized effects caused by the implementation of improvement projects and process execution over time. The decision model accounts for the decision makers' risk attitude via the risk-adjusted interest rate, which is an indirect way of accounting for risk. As improvement projects are scheduled over multiple periods, the decision model also considers a multi-period planning horizon. The risk-adjusted interest rate accounts for the time value of money. Having discussed pros and cons of industrialization strategies, the industry experts highlighted that the economic valuation must be aligned with strategic considerations. For example, while process automation and outsourcing promise cost savings, they also cause knowledge drain. A similar argumentation holds for standardization and automation. To account for such considerations as far as possible, the decision model allows for specifying critical thresholds for distinct process characteristics such as the automation and the sourcing ratio.

As for the decision model's assumptions, we assumed that operating outflows for manual work are constant within a period and the process in focus is such mature that the experience curve is at its flat end (A4). As the experience curve effect depends on the cumulated number of instances, it theoretically decreases for each single instance. As a simplification, we calculate the operating outflows once per period based on the cumulated number of instances up to the previous period. This is why operating outflows remain constant within a period. This approach is reasonable for mature processes, as the experience curve gets the flatter the higher the cumulated demand is. The estimation inaccuracy is negligible. Further, treating the operating outflows as constant per period is risk-averse since this means working with higher outflows than necessary.

IV.1.4.3 Prototype Demonstration (EVAL3)

To demonstrate the software prototype, we present an example that relies on discussions with our industry partners from the financial services industry. Owing to confidentiality, all data had to be anonymized and slightly modified. In the example, a period lasts three months. The planning horizon amounts to eight periods and the risk-adjusted interest rate amounts to 2.5%. The overall budget for improving the process in focus was set to 950,000 EUR for the entire planning horizon.

We consider a mortgage loan process and six improvement projects. The process includes the activities advisory, proposal preparation, and contract management. The process starts when a customer gets in contact with the service provider, and ends when a contract is signed. The department in focus works as a cost center and receives an internal transfer price of 650 EUR per advised customer. The demand for the process is primarily driven by the processing time. Time that results from delays caused be the customer is excluded. All input parameters regarding the process characteristics and process performance indicators of the mortgage loan process prior to implementing any improvement project are shown in Table IV.1-1. Besides the process itself, input parameters regarding all pre-selected improvement projects must be collected. All project descriptions and data are shown in Table IV.1-2, where relative and absolute effects are expressed in terms of (∗) and (+/-), respectively. For each project, we estimated effects on the process, interactions, and constraints. The investment outflows of each project comprise a fixed amount as well as a variable amount that depends on the number of process variants and the automation ratio.

Table IV.1-1. Input parameters regarding process characteristics and performance

Process characteristics			Time indicators			Economic indicators		
	N_0	10%		$t_{\text{work},0}^{\text{SR,int,M,man}}$	345 min		$v_0^{\text{SR,int,M,auto}}$	150 EUR
	E_0	0%		$t_{\text{work},0}^{\text{SR,int,M,auto}}$	210 min		$v_0^{\text{SR,int,M,man}}$	718 EUR
	M_0	61%		γ_0^{time}	1.2		Δv_0^{N}	230 EUR
	α_0	90%		$t_{\text{wait},0}^{\text{SR,int}}$	120 min		γ_0^{cash}	1.2
	A_0	30%		$t_{\text{wait},0}^{\text{N}}$	130 min		f_0	900,000 EUR
	φ_0^{auto}	70%		$t_{\text{setup},0}^{\text{N}}$	130 min		a	0.005
	n_0	3		$\Delta t_{\text{work},0}^{\text{N}}$	80 min		p^{SR}	650 EUR

Demand function	$D_y = 5{,}000 \cdot e^{\frac{650}{t_{y-1}^{\text{total}}}} - 8{,}000$

Based on the input parameters, we applied the software prototype that implements the decision model to determine the optimal and worst process improvement roadmap for several scenarios. Table IV.1-3 contains all results. Scenario (A) is the starting point. This scenario serves as foundation for calculating scenarios (B) to (E), varying one process characteristic per scenario (ceteris paribus).

Consider scenario (A) as example: The optimal process improvement roadmap includes five projects and has a value contribution of 3.51 mio. EUR. The worst roadmap would lead to a value contribution of -3.71 mio. EUR. Project (1) is scheduled for period 1 as it strongly increases the automation ratio, leading to major savings since the operational outflows for automated tasks are significantly lower than for manual tasks. In addition to this indirect effect, project (1) directly affects the operational outflows. In period 2, project (6) is scheduled. This project affects the automation ratio and consequently has similar effects as project (1). Implementing this project is reasonable as the automation potential has not yet been completely tapped. In periods 3 to 5, project (3) is scheduled, whose implementation takes three periods. Implementing project (3) after projects (1) and (6) is reasonable as its investment outflows depend on the automation ratio, which is positively influenced by both prior projects. Project (4) is implemented in period 6. This is reasonable as project (4) has a positive stand-alone business case and is independent from the automation ratio.

In period 7, no project is scheduled. Project (5) is mandatory and negatively affects the working time. Therefore, it is consistent to implement this project in the last period of the planning horizon. Project (2) is not included in any optimal roadmap as it does not pay off in the given planning horizon. The investment outflows and the negative effects on the operational outflows exceed the positive effects on waiting time.

As the additional scenarios are based on varying one process characteristic each, we restrict our discussion to the most significant changes compared to scenario (A). In scenario (B), relating more to standardization, the NPV of the optimal roadmap is smaller than in scenario (A). The reason is that, as shown by the master process ratio, more instances are allocated to the more expensive and slower process variants. Thus, project (4) is implemented earlier, reducing the number of process variants and increasing the master process ratio. Project (3) is skipped as its expensive and late effects on waiting time are exceeded by the cheap and early learning curve effects of project (4). Scenarios (C) and (D) show similar results. In scenario (E), project (3) is skipped because its investment outflows also depend on the number of process variants. In scenario (F), the reduced mandatory tasks ratio leads to a high NPV. The reason is that non-routine instances become cheaper and faster. The positive effect on the working time, in turn, highly influences the process demand. Moreover, projects (4) and (6) switch places because reducing the number of process variants not only improves the master process ratio, but also further increases the non-routine ratio. In scenario (G), the NPV is much higher than in all other scenarios. The reason is the increased automation ratio that positively affects the operating outflows and the working time, starting with period 1. Moreover, as the effect of projects (1) and (6) on the automation ratio are relative, their absolute effect is much higher in this scenario.

The demonstration example showed that, based on the prototype, the decision model yields interpretable results. It indicated that the industrialization strategies cannot be reasonably analyzed stand-alone. We were able to consistently compare process improvement roadmaps and scenarios. In addition, the optimal process improvement roadmaps were relatively constant across the scenarios, which is a first hint on the decision model's robustness against estimation errors.

Table IV.1-2. Input parameters regarding pre-selected process improvement projects

Project	Description, direct effects, constraints, investment outflows
(1)	*Process automation* • Effects: increases the automation ratio by 40% (∗), increases operating outflows for automated work by 80 EUR (+), and reduces operating outflows for manual work by 120 EUR (-) • Constraints: no • Investment outflows (in EUR): $120{,}000 + 20{,}000 \cdot A_y$ • Duration: 1 period
(2)	*Introduction of app-based contract approval* • Effects: decreases manual working time of standard/routine instances by 7% (∗) • Constraints: requires prior implementation of project (6) • Investment outflows (in EUR): $200{,}000 + 30{,}000 \cdot n_y$

	• Duration: 2 periods
(3)	*Implementation of workflow management system* • Effects: reduces waiting time for standard/routine and non-routine instances by 30 min (-) and increases fixed outflows by 15,000 EUR (+) • Constraints: no • Investment outflows (in EUR): $140{,}000 + 40{,}000 \cdot n_y - 10{,}000 \cdot A_y$ • Duration: 3 periods
(4)	*Reduction of number of process variants* • Effects: reduces number of process variants by 1 (-), demand is reallocated by 50% (λ) to master process (*), and fixed outflows decrease by 50,000 EUR (-) • Constraints: no • Investment outflows (in EUR): $45{,}000$ • Duration: 1 period
(5)	*Introduction of specific documentation for customer consultancy* • Effects: increases manual working time of standard/routine instances by 10 minutes (+) • Constraints: mandatory project due, latest implementation in period 8 • Investment outflows (in EUR): $80{,}000 + 30{,}000 \cdot n_y$ • Duration: 1 period
(6)	*Update of the advisory software* • Effects: increases automation ratio by 15% (∗) • Constraints: no • Investment outflows (in EUR): $200{,}000$ • Duration: 1 period

Table IV.1-3. Optimal and worst process improvement roadmaps created by the decision model

Scenario	Changes compared to (A)	Optimal result	Worst result
(A)		Roadmap: (1, 6, 3, 3, 3, 4, -, 5) NPV: 3.51 mio. EUR	Roadmap: (5, -, -, -, 3, 3, 3, 6) NPV: -3.71 mio. EUR
(B)	Reduce master process ratio ($M_0 = 33\%$)	Roadmap: (1, 6, 4, -, -, -, -, 5) NPV: 0.57 mio. EUR	Roadmap: (5, -, -, -, 3, 3, 3, 6) NPV: -6.71 mio. EUR
(C)	Increase non-routine ratio ($N_0 = 25\%$)	Roadmap: (1, 6, 4, -, -, -, -, 5) NPV: 0.89 mio. EUR	Roadmap: (5, -, -, -, 3, 3, 3, 6) NPV: -5.81 mio. EUR
(D)	Reduce automation potential ($\varphi_0^{\text{auto}} = 60\%$)	Roadmap: (1, 6, 4, -, -, -, -, 5) NPV: 0.58 mio. EUR	Roadmap: (3, 3, 3, 5, 6, 2, 2, 1) NPV: -4.78 mio. EUR
(E)	Increase number of variants ($n_0 = 5$)	Roadmap: (1, 6, 4, -, -, -, -, 5) NPV: 3.40 mio. EUR	Roadmap: (5, -, -, -, 3, 3, 3, 6) NPV: -3.88 mio. EUR
(F)	Reduce mandatory tasks ratio ($\alpha_0 = 50\%$)	Roadmap: (1, 4, 6, 3, 3, 3, -, 5) NPV: 7.06 mio. EUR	Roadmap: (5, -, -, -, 3, 3, 3, 6) NPV: -1.51 mio. EUR
(G)	Increase automation ratio ($A_0 = 50\%$)	Roadmap: (1, 6, 3, 3, 3, 4, -, 5) NPV: 11.97 mio. EUR	Roadmap: (5, -, -, -, 3, 3, 3, 6) NPV: 4.75 mio. EUR

IV.1.5 Conclusion

In this paper, we examined which projects an organization should implement to improve a distinct process, particularly accounting for process characteristics that reflect how work is performed and organized. To address this research question, we specified and instantiated a decision model in line with the principles of value-based management and project portfolio selection. Assisting in the valuation of process improvement roadmaps, the decision model contributes to the body of prescriptive knowledge on process improvement and process decision-making. Among possible improvement roadmaps, the decision model recommends selecting that with the highest value contribution in terms of the roadmap's expected net present value. The model extends existing approaches to process improvement by not only focusing on process performance (e.g., time, quality, and costs), but by especially accounting for process characteristics that reflect how work is performed and organized (e.g., number of process variants, fraction of non-routine instances, fraction of instances handled externally, degree of automation, and automation potential). This is different compared to other single-/multi-process approaches. The characteristics used in the decision model were inspired by established industrialization strategies, i.e., automation, sourcing, standardization, and flexibility. Hence, the decision model does not only cover one, but any combination of these industrialization strategies. As process improvement projects often refer to more than one industrialization strategy, this is closer to reality compared to existing approaches. Further, linking project effects not only with performance indicators, but also with process characteristics allows for a more detailed planning compared to existing approaches. Beyond providing insights into process value drivers, process characteristics cater for interactions among industrialization strategies and improvement projects. We evaluated the decision model in line with the framework proposed by Sonnenberg and vom Brocke (2012). In this paper, we reported on the results of feature comparison, an expert interview, prototype construction, and a demonstration example including a scenario analysis in order to fulfill the requirements of the evaluation activities EVAL1 to EVAL3.

However, the decision model suffers from limitations that stimulate further research. Some of the decision model's assumptions simplify reality. For instance, the decision model simplifies the treatment of process variants, as the number of internally processed standard/routine instances was assumed to be equally distributed over all process variants. We already discussed the consequences of the assumptions in the evaluation section. In future research, the decision model should be carefully extended, taking into account that it does not aim at predicting the value contribution of a process improvement roadmap best possible, but at providing a framework for consistently comparing multiple process improvement roadmaps in terms of their value contribution. The feature comparison and the expert interview revealed further challenges. The experts highlighted that determining some input parameters, e.g., cash flows on the single process level, is difficult in naturalistic settings. Thus, the decision model will benefit from further evaluation. Particularly real-world case studies such as recommended by evaluation activity EVAL4, where the decision model and the prototype are applied in naturalistic settings, will help gain more experience in data collection and build up a knowledge base. The case studies should also be used to challenge the decision model's usefulness for organizational stakeholders involved in process improvement and the prioritization of improvement projects. In order to enable real-world case studies, the current software prototype should also be extended toward more sophisticated visualization and analysis functionality. With the decision model abstracting from specific application domains, another worthwhile endeavor for future research is to work on domain-specific sets of process characteristics such as for the services or the manufacturing industry. Finally, our long-term research vision is to extend the decision model such that is covers not only multiple projects, but also multiple interdepending processes.

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Appendix

General Setting	
r	Process improvement roadmap
Y	Planning horizon
y	Planning period within the planning horizon
z	Risk-adjusted discount rate
Process Characteristics Layer	
N_y	Non-routine ratio: fraction of process instances classified as non-routine instances
α_y	Mandatory tasks ratio: fraction of mandatory tasks in SR instances
E_y	Sourcing ratio: Fraction of instances handled entirely externally
n_y	Number of context-specific process variants
M_y	Master process ratio: fraction of instances handled by the master process
A_y	Automation ratio: fraction of tasks carried out automatically relative to automation potential
φ_y^{auto}	Automation potential: highest fraction of tasks that can be automated
λ	Fraction of instances shifted to the master process when reducing process variants
Process Performance Layer	
t_y^{total}	Total processing time
$t_{\text{setup},y}$	Setup time: time where resources are prepared for the execution of specific instances
$t_{\text{wait},y}$	Waiting time: queueing and other waiting time
$t_{\text{work},y}$	Working time: time where process tasks are performed
t_y^{SR}	Total processing time of SR instances
$t_y^{\text{SR,ext}}$	Total processing time of SR instances (external handling)
$t_y^{\text{SR,int}}$	Total processing time of SR instances (internal handling)
$t_{\text{wait},y}^{\text{SR,int}}$	Waiting time of SR instances (internal handling)
$t_{\text{work},y}^{\text{SR,int}}$	Working time of SR instances (internal handling)
$t_{\text{work},y}^{\text{SR,int,M}}$	Working time of SR instances (internal handling by the master process)
$t_{\text{work},y}^{\text{SR,int,M,man}}$	Working time of SR instances (internal handling by the master process, manual)
$t_{\text{work},y}^{\text{SR,int,M,auto}}$	Working time of SR instances (internal handling by the master process, automated)
t_y^{N}	Total processing time for non-routine instances
$t_{\text{setup},y}^{\text{N}}$	Setup time for non-routine instances
$t_{\text{wait},y}^{\text{N}}$	Waiting time for non-routine instances

$t^{\mathrm{N}}_{\mathrm{work},y}$	Working time for non-routine instances
$\Delta t^{\mathrm{N}}_{\mathrm{work},y}$	Additional time for executing tasks of non-routine instances
q_y^{total}	Total quality
q_y^{SR}	Quality of SR instances
$q_y^{\mathrm{SR,ext}}$	Quality of SR instances (external handling)
$q_y^{\mathrm{SR,int}}$	Quality of SR instances (internal handling)
$q_y^{\mathrm{SR,int,M}}$	Quality of SR instances (internal handling by the master process)
$q_y^{\mathrm{SR,int,M,man}}$	Quality of SR instances (internal handling by the master process, manual)
$q_y^{\mathrm{SR,int,M,auto}}$	Quality of SR instances (internal handling by the master process, automated)
q_y^{N}	Quality of non-routine instances
q^{max}	Upper quality boundary: highest level of process quality that can be reached
γ_y^{time}	Performance multiplier regarding master process and variants concerning time
γ_y^{qual}	Performance multiplier regarding master process and variants concerning quality
γ_y^{cash}	Performance multiplier regarding master process and variants concerning outflows
Economic Valuation Layer	
I_y	Investment outflows
f_y	Fixed outflows
$f_y^{\mathrm{SR,int}}$	Fixed outflows of SR instances (internal handling)
$f_y^{\mathrm{SR,ext}}$	Fixed outflows of SR instances (external handling)
f_y^{N}	Fixed outflows of non-routine instances
D_y	Expected number of process instances to be handled
p	Operating inflows
p^{SR}	Sales or transfer price of SR instances
p^{N}	Sales or transfer price of non-routine instances
v_y	Operating outflows
$v_y^{\mathrm{SR,ext}}$	Operating outflows of SR instances (external handling)
$v_y^{\mathrm{SR,int,V}}$	Operating outflows of SR instances (internal handling by a process variant)
$v_y^{\mathrm{SR,int,V,man}}$	Operating outflows of SR instances (internal handling by a process variant, manual)
$v_y^{\mathrm{SR,int,M}}$	Operating outflows of SR instances (internal handling by the master process)
$v_y^{\mathrm{SR,int,M,man}}$	Operating outflows of SR instances (internal handling by the master process, manual)
$v_y^{\mathrm{SR,int,M,auto}}$	Operating outflows of SR instances (internal handling by the master process, automated)
v_y^{N}	Operating outflows of non-routine instances
Δv_y^{N}	Additional operating outflows for non-routine instances
a	Constant elasticity used for the calculation of experience curve effects

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IV.2 Roadmap to flexible Service Processes – A Project Portfolio Selection and Scheduling Approach

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Abstract *Process flexibility has evolved into a desired corporate capability as it promises to cope with demand uncertainty and variety. Particularly service processes have a high intrinsic need for flexibility. Many approaches have been proposed to determine the business value and an appropriate level of flexibility for service processes. Most of these approaches focus on a distinct flexibility type and on single projects for implementing flexible service processes. The question how to reasonably combine flexibility projects has not been addressed yet. Moreover, most approaches do not conduct a full-fledged economic analysis of process flexibility. We therefore propose a decision model that helps determine an optimal flexibility roadmap, i.e., a scheduled portfolio of flexibility projects with different effects on service processes. The decision model accounts for different request types (i.e., runners, repeaters, and strangers), different capacity types (i.e., internal, external, dedicated, and flexible), different flexibility types (i.e., volume and functional), and related project archetypes. The decision model was evaluated using feature comparison, prototype construction, and a demonstration example including an extensive scenario analysis.*

Keywords Service processes, process flexibility, decision model, value-based management.

IV.2.1 Introduction

Services are the biggest and most strongly growing business sector in all industrial nations (Fitzsimmons and Fitzsimmons, 2013; OECD Publishing, 2012). Nevertheless, services are particularly susceptible to demand uncertainty and variety, two challenges flexible service processes promise to address (Goyal and Netessine, 2011). With flexibility becoming an ever more desired corporate capability, service providers heavily invest in flexibility (Neuhuber et al., 2013). More flexible service processes, however, are not necessarily better (He et al., 2012). Rather, the appropriate level of service process flexibility depends on the characteristics of the service processes under investigation, their business environment, and the economic effects of investing in service process flexibility (van Biesebroeck, 2007).

Beyond technical and conceptual advances, many approaches have been proposed to valuate and determine an appropriate level of service process flexibility (Kumar and Stylianou, 2014). Braunwarth et al. (2010) help insurance companies determine whether claims should be handled automated and standardized or manually and flexibly. Their optimization model relies on the expected present value of the short-time cash effects and the long-term effects on customer satisfaction in terms of changes in the customer equity. Due to its focus on runtime decision support, the model neglects investments in flexibility. Afflerbach et al. (2014) consider a superior and an inferior service process in terms of profit margin. Accounting for cash flows as well as for process characteristics such as risky demand, criticality, similarity, and variability, their optimization model analyses which fractions of flexible capacity maximize the risk-adjusted expected net present value (NPV) of both processes. Dorsch and Häckel (2014) consider service processes parts of which can be outsourced via different models of capacity supply. Using discrete event simulation, they investigate how to combine different models of capacity supply to cope with risky demand in a manner that minimizes the total cost of service operations. Dorsch and Häckel focus on cost-driven service processes, a restriction that covers a small subset of services only. Neuhuber et al. (2013) help service providers determine the optimal level of volume and functional flexibility. Despite its focus on the positive economic effects of process flexibility, Neuhuber et al.'s model is restricted to a single period and to deterministic cash flows. Moreover, the flexibility of service processes is measured in terms of two flexibility levels between zero and one, a formalization that can hardly be assessed in real-world scenarios and requires flexibility projects to be ordered in advance. Schober and Gebauer (2011) present a real options-based model for valuating information systems flexibility while considering uncertainty, variability as well as time-criticality as properties of the involved processes. They take on a stochastic perspective in order not to underestimate the value of flexibility. Nevertheless, they only cover the cost effects of flexibility. The literature on project portfolio selection (PPS) also contains real options-based approaches that deal with flexibility (Benaroch and Kauffman, 1999; Huchzermeier and Loch, 2001). These approaches do not directly address service process flexibility.

Moreover, they focus on determining the value added of flexibility in planning or the value of risk mainly based on single objective models, neglecting for example intra-temporal interactions among projects or mandatory projects (Frey and Buxmann, 2012).

This analysis reveals the following research gap: First, most approaches do not conduct a holistic economic analysis of service process flexibility. Most approaches that incorporate positive effects do this in hard-to-measure way or neglect their stochastic and long-term nature. Second, most approaches focus on a single flexibility type, mostly volume flexibility, and conduct detailed analyses regarding a single flexibility project (e.g., outsourcing or capacity reallocation). The challenge of how to combine projects that refer to different flexibility types has not been addressed yet. Approaches that consider multiple flexibility types and projects stay on a high level of abstraction. The resulting research question is as follows: *Which flexibility projects should a service provider implement in which order to achieve an appropriate level of flexibility for its service processes in line with economic principles?*

As a first step to answer this question, we propose a decision model for valuating flexibility roadmaps in line with the principles of project portfolio selection and value-based management (VBM). A flexibility roadmap is a scheduled portfolio of flexibility projects. Flexibility projects refer to volume or functional flexibility and differently affect a service provider's capacity configuration as well as the performance of the service process under consideration. As the decision model shows characteristics of a model and a method, we adopt the design science research paradigm and cover the following phases: identification of and motivation for the research problem, objectives of a solution, design and development, and evaluation (Peffers et al., 2008). In the design and development phase, we use normative analytical modelling to build the decision model (Meredith et al., 1989). With this paper, we also extend our prior research on business process flexibility and the development of business process management capabilities (Afflerbach et al., 2014; Lehnert et al., 2014).

The paper is organized as follows: First, we sketch the foundations of service process flexibility, PPS, and VBM as theoretical background, and derive respective requirements. We then introduce the decision model and report on feature comparison, prototype construction, and a demonstration example. We conclude by presenting key results, limitations, and issues for future research.

IV.2.2 Theoretical Background and Requirements

IV.2.2.1 Flexible service processes

Services are intangible experiences typically defined via criteria such as immateriality, inseparability of production and consumption, and integration of customers in the value creation process (Fitzsimmons and Fitzsimmons, 2013). We focus on information-intensive services that contain many information processing tasks and, thus, have a high potential for IT support and automation (Apte and Mason, 1995; Porter and Millar, 1985). The service value creation process splits into three phases (Alter, 2010). Service providers first create awareness for their services and customers become aware of their need. Both parties then negotiate their commitments and co-create the service. The last phase is called service delivery. Service requests split into runners, repeaters, and strangers (Johnston et al., 2012), a classification that complies with the standard, routine, and non-routine process scheme proposed by Lillrank (2003). Runners are standard activities with well-defined inputs and outputs found in high volume operations. Repeaters are routine activities composed of standard activities. Neither runners nor repeaters require substantial changes in the service process before or during execution, which is why they can be processed similarly (Neuhuber et al., 2013). Strangers are non-standard activities triggered by extraordinary requests whose input and output variety cannot be entirely captured before execution. Strangers thus require preparatory activities and changes in the service process before and during execution.

The performance of business processes in general and of service processes in particular can be assessed in terms of time, cost, quality, and flexibility, the dimensions of the Devil's Quadrangle (Dumas et al., 2013). The Devil's Quadrangle is also used for assessing the effects of process redesign projects, including flexibility projects. Each dimension of the Devil's Quadrangle must be operationalized by specific performance indicators. A prominent time indicator is cycle time, i.e., the time required to handle a request end-to-end. We refer to the cycle time as total service time. Indicators of the cost dimension, which also includes positive economic effects, are turnover, revenue, cash inflows or outflows. Quality splits into internal and external quality that can be measured in terms of error rates and customer satisfaction, respectively. Internal and external quality are closely related to the time dimension, as customer satisfaction is driven by expectations and experiences about time and error-induced rework increases the total service time (Anderson et al., 1994; Ray and Jewkes, 2004). The flexibility of a service process can be measured in terms of time as well (Neuhuber et al., 2013).

The preceding discussion in mind, time is a critical performance dimension of service processes. From a single customer's perspective, a service creates value if it is delivered within a certain time. From the service provider's perspective, the value of a service decreases with the total service time as customers have different preferences regarding time. In line with the effect of time on customer satisfaction, excessive total service time – or the expectation thereof – may decrease demand (Fitzsimmons and Fitzsimmons, 2013). The total service time splits into waiting, set-up, and processing time. Customers must wait if demand exceeds capacity (Gross et al., 2008). The set-up time refers to the period of time where the service provider has not yet started to process the request, but is already preparing employees, devices, machines, processes, or systems (Cheng and Podolsky, 1996). Set-up time has to be considered for complex requests, such as strangers. The processing time relates to the period where the service is co-created with the customer (Curry and Feldman, 2011).

Flexibility refers to the ability of a “system to react to or to anticipate system or environmental changes by adapting its structure and/or its behaviour considering given objectives” (Wagner et al., 2011, p. 811). Process flexibility is a hybrid form of volume and functional flexibility, allowing processes to cope with risky demand and create different as well as unplanned outputs (Afflerbach et al., 2014). This definition also applies to services processes (Johnston et al., 2012). Volume flexibility enables to “increase or decrease production above and below the installed capacity” (Goyal and Netessine, 2011, p. 182). Functional flexibility enables delivering the desired output variety (Anupindi et al., 2012). This definition of process flexibility requires adopting a broad process understanding that, following Alter’s (2013) work system model, includes the resources and people involved in process execution.

When implementing process flexibility, it is worthwhile to analyse how volume and functional flexibility can be achieved. Mainly studied from a capacity and revenue management perspective, volume flexibility includes demand- and supply-side measures. While demand-side measures segment and deskew demand, supply-side measures focus on hedging and turning fixed into variable costs. Exemplary demand-side measures are dynamic pricing, reservation systems, and incentives on off-peak demand (Jerath et al., 2010). Supply-side measures include increased customer integration, enhanced process efficiency, service process automation, capacity sharing, outsourcing of excess demand, IT-based cross-training, and off work shift scheduling (Fitzsimmons and Fitzsimmons, 2013; Jack and Raturi, 2002). Functional flexibility has a rich tradition in workflow management (Reichert and Weber, 2012). Strategies for implementing functional flexibility are flexibility-by-design, flexibility-by-deviation, flexibility-by-underspecification, and flexibility-by-change (Schonenberg et al., 2008). Flexibility-by-design allows for choosing among predefined execution paths, whereas flexibility-by-deviation enables temporarily adapting a process at runtime. Flexibility-by-underspecification allows for completing a process at runtime. Flexibility-by-change enables to cope with events that cannot be addressed by temporary deviations. From a process design perspective, functional flexibility is established via configurable process models and modular design (Gottschalk et al., 2007). From a resource perspective, functional flexibility is achieved via extensive training, multi-purpose machines, process-aware information systems, and service-oriented architectures. Against this background, we derive the following requirement:

(R.1) *Service process flexibility*: To determine the optimal flexibility roadmap, (a) projects referring to functional and volume flexibility must be considered. Furthermore, (b) drivers that cover relevant characteristics of the service process under consideration and its environment must be included.

IV.2.2.2 Project portfolio selection

The literature includes many approaches to PPS (Lee and Kim, 2000; Yu et al. 2012) and project scheduling (Carazo et al., 2010; Perez and Gomez, 2014). Some approaches are qualitative, others are quantitative (Frey and Buxmann, 2012). Qualitative approaches typically propose reference processes, instead of concrete methods (Archer and Ghasemzadeh, 1999; Jefferey and Leliveld, 2004). PPS is the activity "involved in selecting a portfolio, from available project proposals [...], that meets the organization's stated objectives in a desirable manner without exceeding available resources or violating other constraints" (Archer and Ghasemzadeh, 1999, p. 208). The PPS process includes five stages: pre-screening, individual project analysis, screening, optimal portfolio selection, and portfolio adjustment (Archer and Ghasemzadeh, 1999). In the pre-screening stage, projects are checked with respect to whether they align with the organization's strategy. During individual project analysis, each project is evaluated stand-alone regarding pre-defined criteria. In the screening stage, all projects are eliminated that do not satisfy the pre-defined criteria. The optimal portfolio selection stage determines the project portfolio that meets the pre-defined criteria best.

Considering interactions is challenging, but necessary for making PPS decisions (Frey and Buxmann, 2012; Lee and Kim, 2001). Interactions among IT/IS projects can be classified according to three dimensions, i.e., inter-temporal vs. intra-temporal, deterministic vs. stochastic, and scheduling vs. no scheduling (Kundisch and Meier, 2011). Intra-temporal interactions affect the planning of single portfolios, whereas inter-temporal interactions influence today's decision-making based on potential follow-up projects (Gear and Cowie, 1980). Inter-temporal interactions result from effects that depend on the sequence in which projects are implemented (Bardhan et al., 2004). Interactions are deterministic if all parameters are assumed to be known with certainty or were estimated as single values. If parameters are uncertain and follow some probability distribution, interactions are considered stochastic (Medaglia et al., 2007). Scheduling interactions occur if projects may start at different points. Therefore, we derive the following requirement:

(R.2) *Project portfolio selection*: To determine the optimal flexibility roadmap, it is necessary (a) to evaluate available flexibility projects stand-alone prior to portfolio selection and (b) to consider interactions among these projects.

IV.2.2.3 Value-based management

Building on the work of Rappaport (1986), Copeland et al. (1990), and Stewart (1991), VBM sets the maximizing of the long-term company value as the primary objective for all business activities. The company value is based on future cash flows (Rappaport, 1986). To claim value-based management to be implemented, companies must not only be able to quantify the company value on the aggregate level, but also the value contribution of single activities and decisions. In addition, decisions must be based on cash flows, consider risks, and incorporate the time value of money to comply with the principles of VBM (Buhl et al., 2011). Depending on the decision situation and the decision makers' risk attitude, there are accepted objective functions for value-based decision-making (Berger, 2010). In case of certainty, decisions can be made based on the NPV of future cash flows. In case of risk with risk-neutral decision makers, decisions can be made based on the expected

NPV. In case of risk-averse decision makers, decision alternatives can be valuated using the risk-adjusted expected value of the NPV or using a risk-adjusted interest rate. This leads to the following requirement:

(R.3) *Value-based management*: The optimal flexibility roadmap is the roadmap with the highest value contribution. To determine the value contribution of a flexibility roadmap, one has to account (a) for the cash flow effects of the projects included in the roadmap, (b) for the decision makers' risk attitude, and (c) for the time value of money.

IV.2.3 Decision Model

When introducing the decision model, we first outline the general setting including request and capacity types as well as indicators for the performance of the service process under investigation. We then present the project archetypes and integrate all effects into an economic objective function.

IV.2.3.1 Request and capacity types

As unit of analysis, we consider a single service process and focus on the service delivery phase from a supply-side perspective. In line with the characteristics of runners, repeaters, and strangers, we distinguish a joint service process variant for runners and repeaters (RR) and another variant for strangers (S). With all request types referring to the same service process, we express the relationship between both process variants in terms of the fraction of mandatory tasks $\beta \in]0;1]$ from the runner/repeater process variant that are also included in the stranger variant. If almost all tasks of the runner/repeater variant are mandatory, β is close to 1. Consider that β is a one-sided measure that takes on a runner/repeater perspective. It cannot take on the stranger perspective because strangers include additional and potentially request-specific tasks whose amount cannot be foreseen before execution (Johnston et al., 2012).

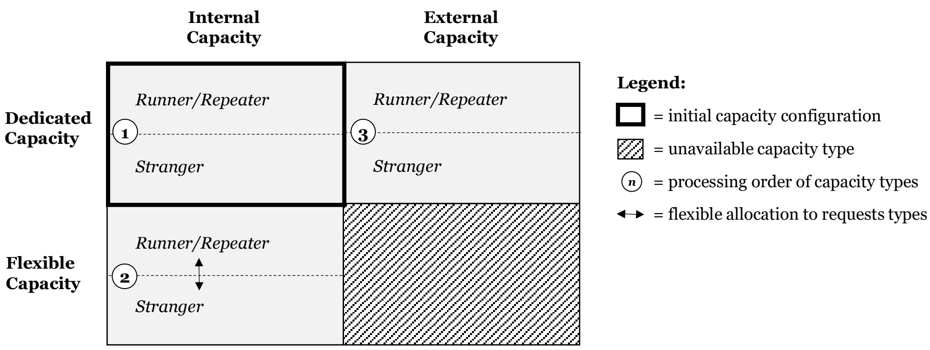

Figure IV.2-1. The service provider's capacity configuration.

In each period of the planning horizon, the service provider disposes of a distinct capacity configuration (Figure IV.2-1). Accounting for our focus on the supply side, the capacity configuration may include different capacity types, i.e., dedicated and flexible capacity as well as internal and external capacity. For our purposes, we neglect external flexible capacity. The capacity of a distinct type denotes the maximum number of related requests the service provider can serve per period. Internal and external capacity refer to the fact that service requests are served using the service provider's own resources or the resources of a third party (Dorsch and Häckel, 2014). Dedicated capacity is assigned to either runner/repeater or stranger requests (e.g., using specifically trained employees, special-purpose machines, or IT services). Flexible capacity can be used for handling both runner/repeater requests and strangers (e.g., using cross-trained employees, multi-purpose machines, and configurable IT services) (Jordan and Graves, 1995).

Assuming that one flexible capacity unit can handle one runner/repeater request, the exchange rate ε indicates how many units are needed to handle a stranger request (Afflerbach et al., 2014). As for external capacity, the service provider can choose between two models of capacity supply, i.e., non-scalable and scalable capacity (Aksin et al., 2008). In case of non-scalable capacity, the service provider increases its dedicated internal capacity for runner/repeater or stranger requests by a fixed amount of capacity units for which it pays a fixed amount of money. As for scalable capacity, the service provider increases its dedicated internal capacity for runner/repeater or stranger requests by a variable, but capped amount of capacity units. The amount of money the service provider must pay depends on how many capacity units it actually used in a distinct period. All capacity types can be changed by implementing flexibility projects. Table IV.2-1 summarizes the relevant mathematical variables. In addition, we assume:

A1: Each service request is handled entirely internally or externally. For each request type, the capacity allocation policy is: internal dedicated capacity, internal flexible capacity, external non-scalable or scalable capacity. In the initial period of the planning horizon $y = 0$, the capacity configuration only includes dedicated internal capacity.

Capacity type	Request type	Capacity	Total service time	Variable cash outflows	Fixed cash outflows
Internal dedicated	RR	$C_{\mathrm{RR},y}^{\mathrm{int}}$	$t_{\mathrm{RR},y}^{\mathrm{int}}$	$v_{\mathrm{RR},y}^{\mathrm{int}}$	$f_{\mathrm{RR},y}^{\mathrm{int}}$
	S	$C_{\mathrm{S},y}^{\mathrm{int}}$	$t_{\mathrm{S},y}^{\mathrm{int}}$	$v_{\mathrm{S},y}^{\mathrm{int}}$	$f_{\mathrm{S},y}^{\mathrm{int}}$
External dedicated	RR	$C_{\mathrm{RR},y}^{\mathrm{ext}}$	$t_{\mathrm{RR},y}^{\mathrm{ext}}$	$v_{\mathrm{RR},y}^{\mathrm{ext}}$	$f_{\mathrm{RR},y}^{\mathrm{ext}}$
	S	$C_{S,y}^{ext}$	$t_{\mathrm{S},y}^{\mathrm{ext}}$	$v_{\mathrm{S},y}^{\mathrm{ext}}$	$f_{\mathrm{S},y}^{\mathrm{ext}}$
Flexible	RR + S	C_{y}^{flex}	t_{y}^{flex}	v_{y}^{flex}	f_{y}^{flex}

y: distinct period of the planning horizon

Table IV.2-1. Mathematical variables related to capacity types.

IV.2.3.2 Performance of the service process

The performance of the runner/repeater and the stranger process variants is evaluated regarding the dimensions of the Devil's Quadrangle (Dumas et al., 2013). To capture the effects of flexibility, we cover the dimensions time and cost. Though acknowledging the importance of service quality, we refrain from modelling quality explicitly because external quality is already in parts driven by time. We also consider the internal quality of runner/repeater and stranger requests to be constant throughout the planning horizon and not to be affected by implemented flexibility projects. Below, we first introduce the performance effects that only depend on the request type. We then discuss performance effects that also depend on the capacity type. Relevant mathematical variables regarding the capacity types are shown in Table IV.2-1.

The cash inflows of the service process only depend on the request type. The service process creates inflows in terms of the sales price. The sales price is p_{RR} for runner/repeater requests and p_{S} for stranger requests. The cash inflows of strangers exceed those of runner/repeater requests as customers are willing to pay a premium for more complex services ($p_{\mathrm{RR}} < p_{\mathrm{S}}$). In line with our focus on the supply side of service delivery, we consider the sales prices as given and constant.

The total service time as well as the variable and fixed outflows depend on both the request type and the capacity type. As runner/repeater requests occur more often and are more predictable than strangers, we use the runner/repeater process variant of the service process as benchmark. As for internal dedicated capacity, runner/repeater requests have a total service time and cause variable outflows per execution (e.g., for people and usage of IT services). Internal dedicated capacity for runner/repeater requests also leads to fixed outflows per period (e.g., for wages, resource consumption, and IT support). Depending on which flexibility projects have been implemented, the total service time, the capacity, the variable and the fixed outflows may take different values per period. Stranger requests require additional service time and cause additional variable outflows (e.g., for preparatory activities, additional tasks and resources, and for using more complex IT services) as well as fixed outflows (e.g., for better trained employees, maintenance of multi-purpose machines). As shown in Formula (1) and (2), the charges regarding time and variable outflows are additional to the total service time and variable outflows caused by the mandatory tasks of the runner/repeater process variant.

$$t_{S,y}^{int} = \beta \cdot t_{RR,y}^{int} + \Delta t_{S,y}^{int} \tag{1}$$

$$v_{S,y}^{int} = \beta \cdot v_{RR,y}^{int} + \Delta v_{S,y}^{int} \tag{2}$$

Flexible capacity leads to variable outflows. These outflows equal the cash outflows that occur for handling runner/repeater and stranger requests by means of internal dedicated capacity. The total service time basically equals the total service times in case of internal dedicated capacity. However, we include an overhead factor $\alpha \in [1; \infty[$ that arises because cross-trained employees typically do not have enough routine to execute service processes as fast and in the same quality as dedicated employees (Pinker and Shumsky, 2000). This leads to a total service time for flexible capacity as shown in Formula (3). Based on our knowledge about the total service times of runner/repeater requests and strangers that are handled via internal dedicated capacity, we can calculate the exchange rate as shown in Formula (4). Flexible capacity also leads to fixed outflows per period.

$$t_y^{flex} = \begin{cases} \alpha \cdot t_{RR,y}^{int} \text{ } in\ case\ of\ a\ runner/repeater\ request \\ \alpha \cdot \left(\beta \cdot t_{RR,y}^{int} + \Delta t_{S,y}^{int}\right) in\ case\ of\ a\ stranger\ request \end{cases} \tag{3}$$

$$\varepsilon = \frac{\beta \cdot t_{RR,y}^{int} + \Delta t_{S,y}^{int}}{t_{RR,y}^{int}} \tag{4}$$

Finally, the external capacity for handling runner/repeater requests causes fixed outflows, variable outflows, and has a total service time. The same holds true for external capacity that is dedicated to stranger requests. As these values are negotiated separately with the external service provider and specified in terms of service level agreements, the time and cash outflow values for external capacity are not derived from their internal counterparts.

Risky demand is an essential driver of service process flexibility. Complying with its effect on quality, the total service time transitively drives the demand. We model the periodic demand of the service process as a normally distributed random variable (Buhl et al., 2011; He et al., 2012). On the assumption that the service provider's customers make their purchase decisions only based on the total service time, the expected demand in a distinct period depends on the average total service time that could be observed by the service provider's customers in the previous period. We do not consider further inter-temporal demand effects, e.g., that customers whose requests cannot be served in a distinct period are such dissatisfied that they churn and place all future requests at another service provider – even if the average total service time decreases. That is, demand that cannot be served based on the service provider's capacity configuration is discarded without any further negative effects. Waiting time therefore plays a subordinate role in the total service time. Moreover, we do not distinguish between a total service time for runner/repeater and stranger requests because customers do not necessarily know whether their requests are treated as runner/repeaters or strangers from an internal service delivery perspective. Beyond risky demand, the proportion of stranger requests can vary in each period in line with the very nature of strangers. We treat the proportion of strangers as uniformly distributed between a service-specific lower and upper boundary. As, in a stable environment, the amount of strangers is much smaller than the amount of runner/repeater requests, the upper boundary of stranger requests relative to the demand is much smaller than one. Our considerations about the demand of the service process are summarized in assumption A.2. Based on these insights, we can derive the number of service requests to be handled as runners/repeaters or strangers in a distinct period as shown in Formula (5) and (6).

A2: The periodic demand $\widetilde{D}_y \sim N\left(\mu_y; \sigma^2\right)$ is normally distributed. The expected demand depends on the average total service time of the previous period $t_{\text{total},y-1}$. With the function $g\left(t_{\text{total},y}\right)$ translating the average total service time into an expected demand, it holds $\mu_y =$

$g(t_{\text{total},y-1})$. The proportion of stranger requests $\tilde{X} \sim \mathcal{U}(a;b)$ follows a uniform distribution with a and b as service-specific lower and upper boundaries ($0 < a, b < 1, a < b, b \ll 1$).

$$\widetilde{D}_{RR,y} = (1 - \tilde{X}) \cdot \widetilde{D}_y \tag{5}$$

$$\widetilde{D}_{S,y} = \tilde{X} \cdot \widetilde{D}_y \tag{6}$$

The average total service time depends on how many runner/repeater and stranger requests are handled by which capacity type. As the number of runner/repeater and stranger requests may exceed the available capacity, we need the number of served requests as specified in Formula (7) and (8) to valuate flexibility projects. Thereby, $\widetilde{D}^{\text{flex}}_{\text{svd,RR},y}$ and $\widetilde{D}^{\text{flex}}_{\text{svd,S},y}$ represent the number of runner/repeater and stranger requests served via flexible capacity. On this foundation, we can calculate the average total service time as shown in Formula (9), where the variables d represent concrete demand realizations.

$$\widetilde{D}_{svd,RR,y} = \widetilde{D}^{int}_{svd,RR,y} + \widetilde{D}^{flex}_{svd,RR,y} + \widetilde{D}^{ext}_{svd,RR,y} \tag{7}$$

$$\widetilde{D}_{svd,S,y} = \widetilde{D}^{int}_{svd,S,y} + \widetilde{D}^{flex}_{svd,S,y} + \widetilde{D}^{ext}_{svd,S,y} \tag{8}$$

$$\begin{aligned} t_{total,y} = \Big[&\big(d^{int}_{svd,RR,y} + d^{flex}_{svd,RR,y} \cdot \alpha\big) \cdot t^{int}_{RR,y} + d^{ext}_{svd,RR,y} \cdot t^{ext}_{RR,y} \\ &+ \big(d^{int}_{svd,S,y} + d^{flex}_{svd,S,y} \cdot \alpha\big) \cdot \big(\beta \cdot t^{int}_{RR,y} + \Delta t^{int}_{S,y}\big) + d^{ext}_{svd,S,y} \cdot t^{ext}_{S,y}\Big] \\ &\cdot \frac{1}{d^{int}_{svd,RR,y} + d^{flex}_{svd,RR,y} + d^{ext}_{svd,RR,y} + d^{int}_{svd,S,y} + d^{flex}_{svd,S,y} + d^{ext}_{svd,S,y}} \end{aligned} \tag{9}$$

IV.2.3.3 Project archetypes

In line with our definition of process flexibility, we distinguish volume flexibility projects and functional flexibility projects. Volume flexibility projects enhance the service provider's ability to cope with fluctuating demand. As for internal capacity, volume flexibility projects can directly affect the total service time and the variable outflows related to the handling of runner/repeater requests. They thereby indirectly influence the total service time and variable outflows of the internal capacity dedicated to stranger requests (see Formula 1 and 2) as well as the total service time and the exchange rate of flexible capacity (see Formula 3 and 4). As for external capacity dedicated to runner/repeater and stranger requests, volume flexibility projects can directly influence the total service time and the variable outflows. Overall, volume flexibility projects can directly affect the fixed outflows and capacity of all capacity types. As far as direct effects are concerned, volume flexibility projects have relative effects on the performance indicators regarding internal dedicated capacity and absolute effects on the performance indicators related to all other capacity types. The reason is that, according to assumption A.1, only internal dedicated capacity is part of the service provider's initial capacity configuration. All other capacity types must be set up from scratch first. Moreover, it is very complex and costly to estimate ex ante the absolute effects of all project candidates considering all possible sequences of implementation (Project Management Institute, 2008). From a roadmap perspective, relative effects must be linked multiplicatively with the performance indicators of the service process, whereas absolute effects are linked additively (Lehnert et al., 2014). Depending on the project at hand, the effects of volume flexibility projects can be positive, negative, or neutral. This allows for covering many different constellations. For instance, there are volume flexibility projects such as process efficiency projects that only directly affect the dedicated internal capacity by reducing the total service time, while decreasing variable outflows with potentially no effect on fixed cash outflows. Other projects may reduce fixed outflows while leaving variable outflows and the total service time unchanged. It is also possible for a volume flexibility project to affect two capacity types. For example, a project can reduce internal dedicated capacity while adding external capacity. A concrete example is the introduction of flexible work contracts, a project that reduces fixed outflows and increases variable outflows. As another example, cross-training employees would positively affect volume flexibility as employees are enabled to handle both runner/repeater and stranger requests. Cross-training would therefore decrease dedicated capacity while adding flexible capacity. All volume flexibility projects cause investment outflows (e.g., for cross-training and related IT support, automating the service process, or integrating an external service provider into one's IT landscape).

Functional flexibility projects affect the service provider's ability to better handle stranger requests by means of internal capacity dedicated to strangers. Therefore, functional flexibility projects can directly influence the respective fixed outflows, the additional time, and the additional variable outflows needed to deal with stranger requests as well as the internal capacity dedicated to strangers (see Formula 1 and 2). Due to the effect on the additional time, functional flexibility projects indirectly affect the exchange rate (see Formula 4). Depending on the project at hand, the effects can again be positive, negative, or neutral. In each case, they are expressed in relative numbers because, according to assumption A.1, internal capacity dedicated capacity already exists in the initial capacity configuration. As an example from a resource perspective, consider the introduction of an enterprise wiki. Operating such a system reduces the variable outflows as well as the total service time while increasing dedicated capacity. All functional flexibility cause investment outflows (e.g., for establishing adequate IT support).

IV.2.3.4 Objective function

To increase the flexibility of the service process, the service provider can invest in flexibility projects. The service provider aims to select the optimal flexibility roadmap, i.e., the roadmap with the highest value contribution, from a set of pre-defined project candidates. The service provider thus determines which project candidates should be implemented in which order. We allow for only one flexibility project to be implemented per period, a feasible restriction as only one service process is considered. Moreover, all flexibility projects can be finished within one period such that their effects become manifest at the beginning of the next period (Lehnert et al., 2014). When determining the optimal flexibility roadmap, the service provider also has to set the relevant planning horizon Y.

Due to the inter-temporal interactions among flexibility projects, capacity types, and request types, the effects of some flexibility projects depend on those projects that have been implemented in prior periods, i.e., implementing the same projects in different sequences leads to different effects and to roadmaps with different value contributions (Pierson, 2000). We assume:

A3: One project can be implemented per period. All projects can be finished within a single period. The effects of all project candidates have been determined in the individual project analysis stage of the PPS process. Moreover, the candidates have been checked for appropriate fit regarding the service process in the pre-screening stage.

To determine the value contribution of a flexibility roadmap r in line with the principles of PPS and VBM, we must compute the expected cash flows for each period of the planning horizon, discount these expected periodic cash flows using a risk-adjusted interest rate z, and then cumulate the discounted cash flows (Buhl et al., 2011). For each period, the cash flows split into investment outflows for implementing the respective project O_y^{inv}, fixed outflows, and an operating cash flows. The operating cash flows for runner/repeater as well as for stranger requests results from the served demand that realizes for the average total service time observed in the previous period and the capacity configuration available in the respective period as well as from a contribution margin. The contribution margin, in turn, depends on the price of the respective request type and the variable cash outflows. The investment outflows as well as all existing fixed cash outflows are due at the beginning of each period. The operating cash flows, in contrast, are due at the end of each period. This leads to the objective function shown in Formula (10). Note that the total service time is shown indirectly in Formula (10) because it is already included in the periodic demand, which in turn is reflected in the number of requests served per capacity type. Note as well that, if a roadmap contains multiple flexibility projects for a distinct capacity type not included in the initial capacity configuration, the effects of each project must be treated separately. For better readability, the objective function in Formula (10) only accounts for one project of these capacity types each.

$$
\begin{aligned}
&\max_{r} \widetilde{NPV}_r = \\
&-\sum_{y=0}^{Y} \frac{O_y^{inv}}{(1+z)^y} - \sum_{y=0}^{Y} \frac{f_{RR,y}^{int} + f_{S,y}^{int} + f_y^{flex} + f_{RR,y}^{ext} + f_{S,y}^{ext}}{(1+z)^y} \\
&+\sum_{y=0}^{Y} \frac{(p_{RR} - v_{RR,y}^{int}) \cdot \left[E\left(\tilde{D}_{svd,RR,y}^{int}\right) + E\left(\tilde{D}_{svd,RR,flex,y}^{int}\right)\right]}{(1+z)^{y+1}} + \sum_{y=0}^{Y} \frac{(p_{RR} - v_{RR,y}^{ext}) \cdot E\left(\tilde{D}_{svd,RR,y}^{ext}\right)}{(1+z)^{y+1}} \\
&+\sum_{y=0}^{Y} \frac{\left(p_S - (\beta \cdot v_{RR,y}^{int} + \Delta v_{S,y}^{int})\right) \cdot \left[E\left(\tilde{D}_{svd,S,y}^{int}\right) + E\left(\tilde{D}_{svd,S,flex,y}^{int}\right)\right]}{(1+z)^{y+1}} + \sum_{y=0}^{Y} \frac{(p_S - v_{S,y}^{ext}) \cdot E\left(\tilde{D}_{svd,S,y}^{ext}\right)}{(1+z)^{y+1}}
\end{aligned}
\tag{10}
$$

IV.2.4 Evaluation

According to Venable et al. (2012), a variety of methods and patterns are available to evaluate artefacts in design-oriented research. To evaluate the decision model, we discuss the decision model against the requirements derived from the literature, implemented a simulation-based software prototype, and present a demonstration example. Due to space restrictions, we do not present the prototype here.

IV.2.4.1 Feature comparison

The results of feature comparison are shown in Table IV.2-2. The requirements that relate to service process flexibility and VBM are met to the full extent. The requirement that accounts for PPS is covered partly. The resulting need for future research is outlined in the conclusion.

Requirement	**Features of the model**
(R.1) Service process flexibility	The decision model accounts for volume and functional flexibility projects (R.1a). It also considers characteristics related to the service process under investigation and the business environment (R.1b). As for the service process, we distinguish multiple request types, capacity types, and several dimensions of performance. As for the business environment, we account for risky demand as one of the most important flexibility drivers.
(R.2) Project portfolio selection	We consider a set of pre-defined project candidates. We assume that, in the pre-screening stage, all candidates were checked for appropriate strategic fit and that, in the individual project analysis stage, the relative and absolute effects all of candidates have been determined as single values independent from other projects (R.2a). The absolute effects of some projects depend on the projects that have been implemented in prior periods. With the periodic demand and the proportion of strangers per period, we consider stochastic, scheduling, and inter-temporal interactions (R.2b).
(R.3) Value-based management	The value contribution of a flexibility roadmap is based on the expected value of its stochastic NPV using a risk-adjusted interest rate for discounting. The stochastic NPV considers all cash effects that result from volume and functional flexibility projects as well as from service delivery (R.3a). We account for the decision makers' risk attitude when using a risk-adjusted interest rate (R.3b). As flexibility roadmaps comprise multiple projects implemented at different points in time, we also consider a multi-period planning horizon and the time value of money (R.3c).

Table IV.2-2. Results of feature comparison.

IV.2.4.2 Demonstration example

For the demonstration example, we consider a fictitious service process that has a normally distributed periodic demand depending on the total service time (in hours) as shown in Formula (11).

$$\widetilde{D}_y \backsim N\left(1{,}000 \cdot e^{\frac{1}{t_{total,y-1}}}; 150^2\right) \tag{11}$$

The fraction of mandatory tasks that must be executed for runner/repeater and stranger requests amounts to $\beta = 0.6$. For the periodic proportion of strangers, we investigate two different scenarios, i.e., a small and one broad range, as modelled by the uniform distributions $\mathcal{U}(0.1; 0.2)$ and $\mathcal{U}(0; 0.3)$. We calculate the initial total service time in $y = 0$ based on a stranger proportion of $x = 0.15$. As initial capacity configuration, the service provider disposes of $C_{\mathrm{RR},0}^{\mathrm{int}} = 2{,}000$ units of dedicated internal capacity for runner/repeater requests and of $C_{\mathrm{S},0}^{\mathrm{int}} = 180$ units of dedicated internal capacity for stranger requests. The corresponding fixed outflows are $f_{\mathrm{RR},0}^{\mathrm{int}} = 60{,}000$ € and $f_{\mathrm{S},0}^{\mathrm{int}} = 30{,}000$ €. The variable outflows are $v_{\mathrm{RR},0}^{\mathrm{int}} = 80$ € and $\Delta v_{\mathrm{S},0}^{\mathrm{int}} = 100$ €. The service provider calculates with a total service time $t_{\mathrm{RR},0}^{\mathrm{int}} = 1$ h for handling runner/repeater requests using the available capacity as well as with an additional time of $\Delta t_{\mathrm{S},0}^{\mathrm{int}} = 1.1$ h for handling strangers. Customers are willing to pay $p_{\mathrm{RR}} = 200$ € for runner/repeater requests and $p_{\mathrm{S}} = 400$ € for stranger requests. We consider six different projects (Table IV.2-3), thereof five volume flexibility projects and one functional flexibility project. Four projects only have relative effects (exclusively depicted in Table IV.2-4) or absolute effects (exclusively depicted in Table IV.2-5). The other two projects have relative and absolute effects (Table IV.2-4 and Table ***IV***.2-5). The absolute capacity units of project 3 and 5 are calculated (calc.) based on the respective relative effects on the internal capacity during the application of the prototype. For all projects, we estimated optimistic (opt.) and pessimistic (pess.) effects. The difference between the optimistic and the pessimistic scenario is about 10%.

Project n	Description	Type	O^{inv}
1	Outsourcing excess demand of runner/repeater requests to an external service provider	Volume	1,000 €
2	Outsourcing excess demand of stranger requests to an external service provider	Volume	1,000 €
3	IT-based cross-training of employees	Volume	40,000 €
4	Increased process efficiency by means of standardization and automation	Volume	25,000 €
5	Shift from traditional to flexible employment contracts	Volume	30,000 €
6	Implementation and roll-out of an enterprise wiki	Functional	10,000 €

Table IV.2-3. Flexibility projects considered in the demonstration example.

Project n	Scenario	Effect on			
		$f_{\text{RR}}^{\text{int}}$	$C_{\text{RR}}^{\text{int}}$	$f_{\text{S}}^{\text{int}}$	$C_{\text{S}}^{\text{int}}$
3	pess.	0.95	0.88	-	-
	opt.	0.92	0.88	-	-
5	pess.	-	-	0.8	0.6
	opt.	-	-	0.72	0.67

Project n	Scenario	Effect on			
		$v_{\text{RR}}^{\text{int}}$	$t_{\text{RR}}^{\text{int}}$	$\Delta v_{\text{S}}^{\text{int}}$	$\Delta t_{\text{S}}^{\text{int}}$
4	pess.	1	0.96	-	-
	opt.	0.95	0.92	-	-
6	pess.	-	-	0.95	0.9
	opt.	-	-	0.85	0.75

Table IV.2-4. Relative effects of flexibility projects.

Project n	Capacity	Scenario	Capacity units	f_y	v_y^{ext}	t_y^{ext}	α
1	$C_{\text{RR},y}^{\text{ext}}$	pess.	320	0 €	125 €	1.2 h	-
		opt.	350	0 €	120 €	1.1 h	-
2	$C_{\text{S},y}^{\text{ext}}$	pess.	27	7,830 €	0 €	2.0 h	-
		opt.	30	8,400 €	0 €	1.8 h	-
3	C_y^{flex}	pess.	calc.	5,500 €	-	-	1.10
		opt.	calc.	5,000 €	-	-	1.05
5	$C_{\text{S},y}^{\text{ext}}$	pess.	calc.	0 €	255 €	1.85 h	-
		opt.	calc.	0 €	250 €	1.7 h	-

Table IV.2-5. Absolute effects of flexibility projects.

We assume that a planning period lasts one quarter and that the service provider uses a risk-adjusted discount rate of 10.4% per year and 2.5% per quarter for valuating investment decisions. For the planning horizon, we decided to analyse a short and a long planning horizon, i.e., three and eight periods. As for the long planning horizon, we mainly face a project scheduling problem, while project selection becomes more important for the short planning horizon.

Concerning the planning horizon (short vs. long), the stranger range (small vs. broad), and the project effects (optimistic vs. pessimistic), we investigate eight scenarios. For each scenario, we determine the best and the worst roadmap. In sum, there are 229 roadmap candidates for the short planning horizon and 93,289 candidates for the long planning horizon. To determine the stochastic NPV of all roadmap candidates, we simulated 1,000 iterations per candidate using our software prototype. For all scenarios, Table IV.2-6 shows the best and the worst roadmaps in terms of the expected stochastic NPV followed by their relative value contribution. Each roadmap is depicted as a sequence of project indices, where "-" denotes that no project has been scheduled for the respective period.

		Short planning horizon		**Long planning horizon**	
		Small stranger range	**Broad stranger range**	**Small stranger range**	**Broad stranger range**
Best Case	**Opt.**	Project order: 1, 2, - NPV: 570,325 (3.59%)	Project order: 1, -, - NPV: 542,992 (3.90%)	Project order: 1, 4, 2, -, -, -, -, - NPV: 1,473,605 (6.65%)	Project order: 1, 4, 6, 2, -, -, -, - NPV: 1,395,534 (6.58%)
	Pess.	Project order: 1, 2, - NPV: 568,345 (3.23%)	Project order: 1, -, - NPV: 540,822 (3.48%)	Project order: 1, 2, -, -, -, -, -, - NPV: 1,449,779 (4.92%)	Project order: 1, -, -, -, -, -, -, - NPV: 1,369,483 (4.59%)
Worst Case	**Opt.**	Project order: 3, 5, 4 NPV: 401,304 (-27.11%)	Project order: 3, 5, 4 NPV: 382,831(-26.75%)	Project order: 3, 5, -, -, -, -, 6, 4 NPV: 1,085,480 (-21.44%)	Project order: 3, 5, -, -, -, -, 6, 4 NPV: 1,053,524 (-19.54%)
	Pess.	Project order: 3, 5, 4 NPV: 391,942 (-28.81%)	Project order: 3, 5, 4 NPV: 373,872 (-28.46%)	Project order: 3, 5, 4, -, -, -, 6, 1 NPV: 1,038,157 (-24.87%)	Project order: 3, 5, 4, -, -, -, 6, 1 NPV: 1,008,704 (-22.96%)

Table IV.2-6. Results of the demonstration example.

The results of applying the decision model to the demonstration example can be interpreted as follows:

1. In each scenario, the expected stochastic NPV of the best flexibility roadmap differs a lot from the value of the corresponding worst flexibility roadmap. For example, in the optimistic scenario with a long planning horizon and a small stranger range, the expected stochastic NPV is 388,125 € (26%) higher than the expected stochastic NPV of the worst flexibility roadmap. This result corroborates the proposition that the concrete selection of projects and the inter-temporal interactions implied by their sequence of implementation have a large impact on the value contribution.
2. Apart from the differences in the planning horizon, the projects included in the best flexibility roadmap and their sequence of implementation are similar for almost all scenarios. In all eight scenarios, project 1 is the first project being implemented. This is reasonable as the expected demand exceeds the initial capacity for runner/repeater requests in the initial period and project 1 adds dedicated external capacity for runner/repeater requests. Due to

the fact that project 2 refers to external dedicated capacity for stranger requests, it is part of the best flexibility roadmap in all scenarios with a small stranger range. As for a broad stranger range, project 2 is only in the optimistic scenario with a long planning horizon part of the best flexibility roadmap as the proportion of stranger fluctuates more strongly. In the optimistic scenarios with a long planning horizon, project 4 that increases efficiency by means of standardization and automation is implemented. In all other scenarios, project 4 is not part of the best flexibility roadmap. In the optimistic scenarios with a short planning horizon, three periods are not enough to justify the investment outflows for implementing this project. In all pessimistic scenarios, the effects of project 4 are too weak. Project 6, which proposes the implementation of an enterprise wiki, is only implemented in the optimistic scenario with a long planning horizon and a broad stranger range. Project 6 mainly reduces additional time for handling stranger requests. As a result, stranger requests increase and it is reasonable to add dedicated external capacity for stranger requests by implementing project 2 thereafter. It is also notable that the projects 3 and 5 are not included in any best flexibility roadmap. Project 3, which refers to IT-based cross-training for employees, enables flexible capacity and therefore load balancing between runner/repeater and stranger requests. This flexible capacity goes along with higher cash outflows and longer total service time compared to the already existing dedicated internal capacity. In our setting, flexible capacity does not lead to additional value contribution. The reason is that load balancing capabilities are not necessary because the expected demand exceeds the initial capacity in the initial period both for runner/repeater and stranger requests, and therefore no free capacity exists. Project 5 partially transforms internal dedicated capacity for stranger requests into external dedicated capacity for stranger requests. It is not included in a best flexibility roadmap for the same reason as project 3.

3. It can be seen in Table IV.2-6 that not only the sequence of implementation influences the value contribution of a flexibility roadmap. It is also reasonable from an economic point of view not to include all available project candidates.
4. Finally, as the flexibility projects included in the best flexibility roadmaps and the corresponding expected stochastic NPVs do not differ largely in the optimistic and the pessimistic scenarios (1.03% difference on average), we hypothesize that the decision model is robust against minor estimation errors. Such a hypothesis, however, must be checked in future research.

IV.2.5 Conclusion

Against the increasing importance of flexible service processes, we investigated which flexibility projects a service provider should implement in which order to achieve an appropriate level of flexibility. To answer this question, we proposed a decision model that valuates flexibility roadmaps, i.e., portfolios of scheduled flexibility projects with different effects on service processes. The decision model helps select the roadmap with the highest value contribution in a given planning horizon. The value contribution of a flexibility roadmap is expressed in terms of the expected value of the roadmap's stochastic net present value using a risk-adjusted interest rate. The decision model covers a single service process and focuses on how this process performs regarding time, flexibility, and cost. It also distinguishes runners, repeaters, and strangers as request types, handles multiple capacity types such as internal, external, dedicated, and flexible capacity, and considers a stochastic demand and proportion of strangers. As for the evaluation, we discussed the decision model against requirements derived from the literature, built a software prototype, and presented a demonstration that is example based on the prototype.

As the decision model does not meet all requirements to the full extent, its limitations should be subject to future research: As typical for modelling endeavors, some assumptions had to be made that simplify reality. For example, the decision model focuses on a single service process and allows for only one flexibility project per period. It is worthwhile to relax this assumption as, in industry, service processes are part of networks of multiple interconnected processes. One possibility of relaxing this assumption consists in adopting a single-project-per-period-and-process policy. If, across all service processes under investigation, more than one project can be implemented per period, it is necessary to account for intra-temporal interactions (e.g., budget restrictions, mandatory projects, and input-output interactions). Moreover, the effects of flexibility projects are treated as static throughout the planning horizon, an assumption that could be relaxed in future research as well. The decision model would also benefit from real-world case studies to gain experience with estimating the needed parameters and to infer general insights into the behavior of the decision model. Conducting case studies would also benefit from a software tool that extends the current prototype. Such a software tool should be able to handle more complex cases than illustrated in this paper and implement more sophisticated analysis capabilities (e.g., scenario analyses regarding different parameters).

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IV.3 V3PM: A Decision Support Tool for Value-based Process Project Portfolio Management

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Abstract *In the context of Business Process Management (BPM), organizations strive to develop their BPM capability and to improve their individual business processes in an integrated manner. Planning models assist in selecting and ordering implementable BPM- and process-level projects maximizing the firm value, catering for the projects' effects on process performance and for interactions among projects. To facilitate process managers for calculating scenarios of non-trivial complexity, the Value Based Process Project Portfolio Management (V3PM) tool has been developed. The V3PM tool is a stand-alone program that effectively and efficiently selects one project portfolio for which the net present value takes the highest value. It is designed to fulfil a twofold objective: the scientific perspective in terms of an adequate evaluation for existing design science research artefacts as well as the user's point of view in terms of a first step towards a full-featured version for decision support in daily business operations. In this paper, we describe the application's architecture focusing on the data management, the roadmap engine and the graphical user interface. Deeper insights into the functionality for creating and analyzing persistent problem sets highlight the strengths of the V3PM tool as well as its usefulness and practical applicability for decision support.*

Keywords Business Process Improvement, Process-Decision Making, Project Portfolio Management, Business Process Management

IV.3.1 Introduction

IV.3.1.1 Status Quo of Decision Support for Process Improvement

Process orientation is an accepted paradigm of organizational design (Kohlbacher and Reijers, 2013). Due to constant attention from industry and academia, the business process management (BPM) community has developed mature approaches, methods, and tools that, for instance, support process improvement (van der Aalst, 2013; Zellner, 2011). However, only few approaches give guidance on how to put process improvement into practice (Bandara et al., 2015; Shrestha et al., 2015; Ohlsson et al., 2014) mostly sharing a single process as unit of analysis and consequently neglecting interactions among multiple processes. At the same time, the BPM community has been and still is paying ever more attention to BPM itself and the development of organizations' BPM capability (de Bruin and Rosemann, 2005; Poeppelbuss et al., 2015). Research mainly focuses on identifying and grouping the constituents of BPM and developing related capability frameworks (de Bruin and Rosemann, 2007; Rosemann and vom Brocke, 2015; van Looy et al., 2012). Few guidance on how to develop an organization's BPM capability from a theoretical, prescriptive perspective is available (Niehaves et al., 2014; Poeppelbuss et al., 2015). Consequently, there is a lack of approaches that assist organizations in selecting and ordering projects that improve multiple processes and organization's BPM capability in an integrated manner to maximize the firm value, while catering for the projects' effects on process performance and for interactions among projects.

Against this background, we developed two planning models answering differing aspects with our prior research (Lehnert et al., 2014; Linhart et al., 2015). They help valuating so-called BPM roadmaps in line with the principles of project portfolio selection and value-based management. We define a BPM roadmap as a scheduled portfolio of projects an organization should implement. To identify the BPM roadmap that maximizes the company's value, we calculate the BPM roadmaps' net present value (NPV). The BPM roadmap with the highest NPV is the roadmap to be implemented. In Lehnert et al. (2014), we focus on improvement projects for process improvement and BPM capability development in an integrated manner. The planning model takes a multi-process, multi-project, and multi-period perspective while catering for the projects' effects as well as for interactions among projects and processes. Due to the multi-process and multi-project focus, we analyze single processes only in terms of their performance indicators and exclude more detailed process characteristics. In Linhart et al. (2015), we examine how organizations should improve a distinct process via improvement projects with a particular focus on the characteristics of that process. We consider characteristics that capture how work is performed and organized. To restrict the set of admissible BPM roadmaps, this planning model introduces the specification of project-specific (e.g., earliest beginning), process-specific (e.g., critical boundaries for performance indicators), and period-specific constraints (e.g., available budget) that BPM roadmaps must not violate. Due to the single-process perspective, interactions among processes are excluded.

IV.3.1.2 Need for new Prototype / Design Objectives

Multi-process, multi-project, and multi-period perspectives on process improvement lead to non-trivial complexity and call for a useful and easy-to-use decision support tool. Thus, we developed the Value-based Process Project Portfolio Management (V3PM) tool enhancing the prototypes that resulted from our prior research on process improvement and project portfolio selection (Lehnert et al., 2014; Linhart et al., 2015). When developing the tool, we primarily focused on scientific rigour and practical applicability. Following design science research (DSR), our prior work resulted in planning models that comprise the identification of and motivation for the research problem, objectives of a solution, design, and development (cf. Peffers et al., 2007). However, to complete the DSR process, an adequate evaluation of the DSR artefacts that solve the observed problem (e.g., constructs, models, methods, and instantiations; see Hevner et al., 2004) is necessary (cf. March and Storey, 2008; Sonnenberg and vom Brocke, 2012). As result, the design objectives of the V3PM tool focus on the ex post evaluation activities according to the evaluation framework of Sonnenberg and vom Brocke (2012). The V3PM tool is used both for incorporating a proof of concept (EVAL3) and for preparing an application in naturalistic settings to validate its usefulness (EVAL4). Thus, we need an adequate user interface and have to overcome various shortcomings of the existing prototypes. Since no external requirements exist, we focus on internal quality and quality in use as specified in the evaluation criteria of DSR artefacts (Sonnenberg and vom Brocke, 2012) and the quality requirements of systems and software quality (ISO/IEC 25010). Further, we intended to merge the scientific insights of our distinct research streams in one single application. The V3PM tool at its current stage should only be a first step towards a full-featured decision support tool applicable in daily business operations (e.g. from production or service industry).

The V3PM tool was designed as executable program that effectively and efficiently generates all admissible BPM roadmaps, applies the objective function to each admissible roadmap to calculate the NPV, and selects the roadmap which the highest NPV. The V3PM tool was designed to consider the multi-process perspective as well as all improvement effects of Lehnert et al. (2014) in combination with multi-period projects and the integration of constraints as shown in Linhart et al. (2015). Further, an almost unlimited number of projects and processes should be feasible. In view of the necessary performance, we decided for a new software architecture, e.g. persistent and fast data management, as well as for new algorithms, e.g. for a more efficient roadmap generation minimizing existing bottlenecks and providing modularity according to the maintainability. In order to improve usability and satisfaction, a graphical user interface (GUI) just as analysis and visualization functionalities were integrated. We introduced the concept of scenarios to allow the examination of different persistent problem sets based on the combinations of projects and processes. They were designed to simplify data in- and output and to prevent errors. A focussed provision of information as well as in-depth insights in terms of sensitivity analyses improve the decision support.

IV.3.1.3 The Architecture

The V3PM tool is an executable program mainly relying on Java. Its implementation follows a typical 3-tier architecture dividing presentation, business logic and data storage into independent modules due to the modularity and maintainability requirements (Fowler, 2002). Figure IV.3-1 shows the different components: the data collection, the roadmap generation, the roadmap calculation, and the analysis functionalities. The data collection and the analysis functionalities belong to the presentation tier as front-end that consists of multiple GUI components. Therefore, we used the toolkit JavaFX and the related open source project ControlsFX as well as the third party library GraphStream that provide a lot of visualization features needed for the analysis functionalities, particularly for charts and dynamic graphs. The roadmap generation and calculation are part of the business logic. The business logic and the data storage tier represent the back-end of the application. They implement the insights of the decision model as well as database connections for reading and writing data to a persistent storage. The communication across the different layers is performed via defined interfaces. Despite the typical representation of a 3-tier architecture, we first outline the business logic tier (Section IV.3.2) as it is the implementation of our planning models and the core of the V3PM tool. We then introduce the presentation layer (Section IV.3.3) to highlight the extension of the roadmap calculation in terms of analysis and visualization functionalities.

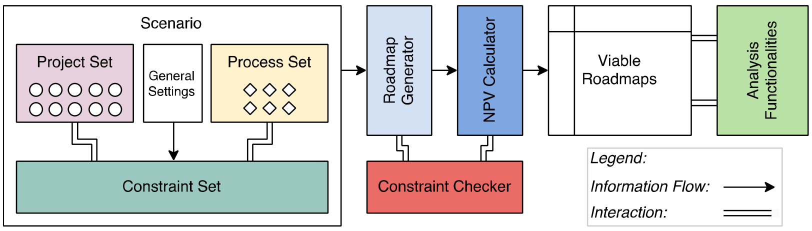

Figure IV.3-1. The components of the business logic

IV.3.2 The Business Logic and the Back-end Side

The business logic tier contains multiple algorithms for the generation, calculation, and analysis of BPM roadmaps considering the projects' effects on process performance and for interactions among projects. The data collection provides the input data in terms of distinct scenarios. Each scenario consists of multiple projects and processes. Each project has specific performance effects that influence one or more processes from the process set. Further a constraint set (e.g., for interactions among projects) and general settings (e.g., the risk-adjusted interest rate) are part of a scenario. For each scenario, the roadmap generator evaluates the potential process and project combinations. The NPV calculator applies the objective function to them resulting in the NPV and additional variables for further in-depth analyses, e.g. scenario analyses, provided by the analysis functionalities. The constraint checker ensures considering only admissible BPM roadmaps during the generation and calculation.

The parts of the business logic that happen before the roadmap calculation demonstrate the most significant differences and improvements compared to the existing prototypes at the back-end side. In the following, we focus on the algorithms of the roadmap generator with particular regard to the performance features and present the prototype's data management functionalities. The scenario component is part of the data management as well as the GUI components in the front-end section.

IV.3.2.1 Constraint-based Roadmap Generation

The roadmap generation based on the user-defined project sets mainly generates lexicographical permutations (Knuth, 2011) in a broader sense. Difficulties arise from the multi-period perspective and the opportunity not to implement any project within distinct periods. Both are not captured by existing java libraries (e.g., `org.paukov.combinatoricslib`, `com.google.common.collect.Collections2`). Thus, we designed a special form of the algorithm. We use containers based on `ArrayList` to record all periods considered for the implementation of a project as well as combinations of these to form the entire roadmaps. Figure IV.3-2 illustrates the roadmap generation including restriction handling in general and exemplifies the roadmap generation considering three potential process improvement projects and a planning horizon of three periods without restrictions. The implementation of project 1 would take one period, for project 2 it would take two periods and for project 3 it would take three periods. The available capacity within the organization allows for two project implementations in parallel.

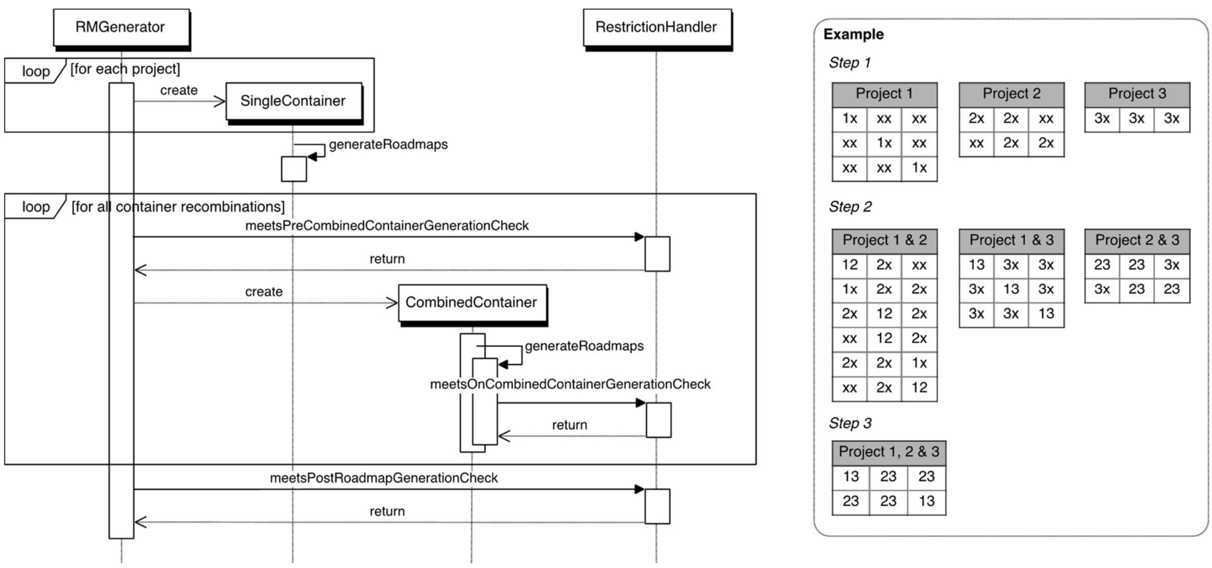

Figure IV.3-2. Roadmap Generation and Restriction Handling

First, the algorithm generates the containers for each single project of the project set. A container includes all possible project schedules due to project duration and planning horizon. In our example, we get three containers. These are the basis for the following combinations. Each cycle forms further containers as Cartesian product of two containers generated beforehand. Finally, recombination leads to $\sum_{k=1}^{n}\binom{n}{k}$ containers (with n = number of projects) and an even larger amount of roadmaps. A tracking mechanism hinders double combinations of containers.

However, not all generated unique roadmaps are admissible due to given constraints, e.g. for organizational, content-related, or regulatory reasons (Linhart et al., 2015). This can be assured by incorporating a constraint check at multiple stages. Project-specific constraints, e.g. earliest beginning or latest completion, can be checked during the generation of the creation. Interactions among projects, e.g. predecessor-successor-relationship, have to be examined afterwards. Unfortunately, the stepwise design of roadmap generation hinders the allocation of some constraints to earlier stages and gives room for further improvements. Nonetheless, the container design allows for fast constraint checks as the distinct included projects are known. Additionally, there is a further check for process- and period-specific constraints, e.g. quality boundaries or budget limits, included in the NPV calculation (see Figure IV.3-3).

Nonetheless, the generation and calculation algorithms have to cope nearly an infinite number of BPM roadmaps. A naturalistic setting including four processes, nine projects, and a planning horizon of five periods that we derived from expert interviews led to 2,7 million potential and, at least, approximately 250,000 admissible roadmaps. To facilitate the needed high throughput in terms of performance as intended in the design objectives, we incorporated a concurrency concept based on the `javafx.concurrent` package. Following this, multiple threads are performed asynchronously or in parallel while updating the user interface, generating roadmaps and calculating the NPVs.

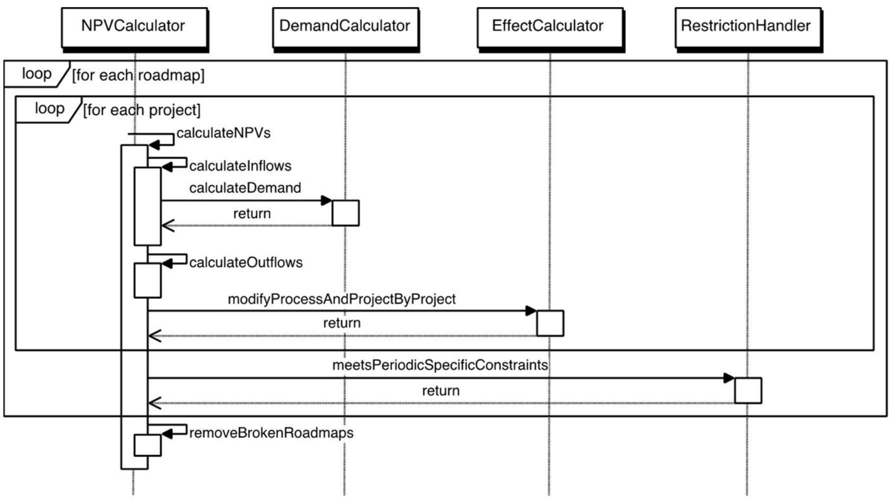

Figure IV.3-3. Roadmap Calculation

IV.3.2.2 The Data Management

The design decisions towards the data management are in line with the performance and usability requirements. We use the database management system (DBMS) SQLite that is often used as the on-disk file format for desktop applications such as financial analysis tools. The DBMS offers high performance, reliability, and security in terms of ISO/IEC 25010 including efficient data access and data integrity (Ramakrishnan and Gehrke, 2003). Due to the sophisticated techniques to store and retrieve the (intermediate) results efficiently, the essential part of computing time remains content-related depending on the planning model, e.g. roadmap generation or NPV calculation, and less affected by the technical environment. Further, based on the DBMS, we were able to introduce a relational data model that provides more usability and flexibility via reuse of data. Once processes and projects have been created, they can be combined in any way for new scenarios whereas constraints are specific for each scenario. Further, the scenario component allows to store different problem instances which can be re-opened, copied, and modified for determining the effect of slight changes on distinct scenarios at any point in time. As data does not have to be entered every time, we expect that the user experience increases.

IV.3.3 Front-end and Functionality of the V3PM Tool

While the concept of the back-end side aims at the product quality, the concept of the front-end side has a strong focus on quality in use (ISO/IEC 25010). A well-structured GUI (Figure IV.3-4) just as selected analysis functionalities assure quality by usability and satisfaction.

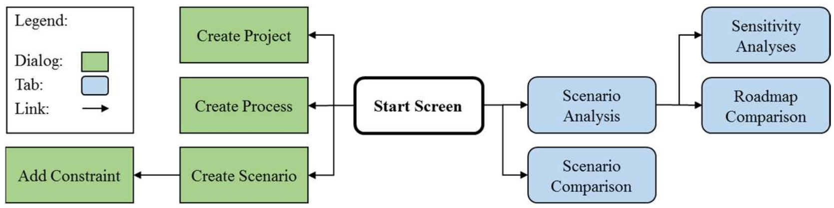

Figure IV.3-4. GUI Navigation Model

IV.3.3.1 The Graphical User Interface (GUI)

The GUI gives a very compact and clean design. The start screen (Figure IV.3-5) as the center of the application provides an overview of the projects, processes, and scenarios. From here, all functions of the V3PM tool can be reached. As shown in Figure IV.3-4, the navigation model follows two approaches that differ optically as well as technically.

Dialogs that open in a new window enable the gathering of further input data (Figure IV.3-6). The provided data entry fields change dynamically due to the selected project type. In case of scenarios, the input is a combination of projects and processes in addition to the information about the interactions and constraints to be considered as well as the general settings (e.g., risk-adjusted interest rate, number of periods in the planning horizon). Here, the GUI also provides usability features in terms of product quality. As it uses referential integrity for error protection, the mapping of projects and processes is only possible for those that have already been created. For the results of the NPV calculation, additional tabs show detailed scenario information. Whereas the dialogs are only visible for a certain time until the input is finished, the tabs remain open for analysis purposes until the user finishes.

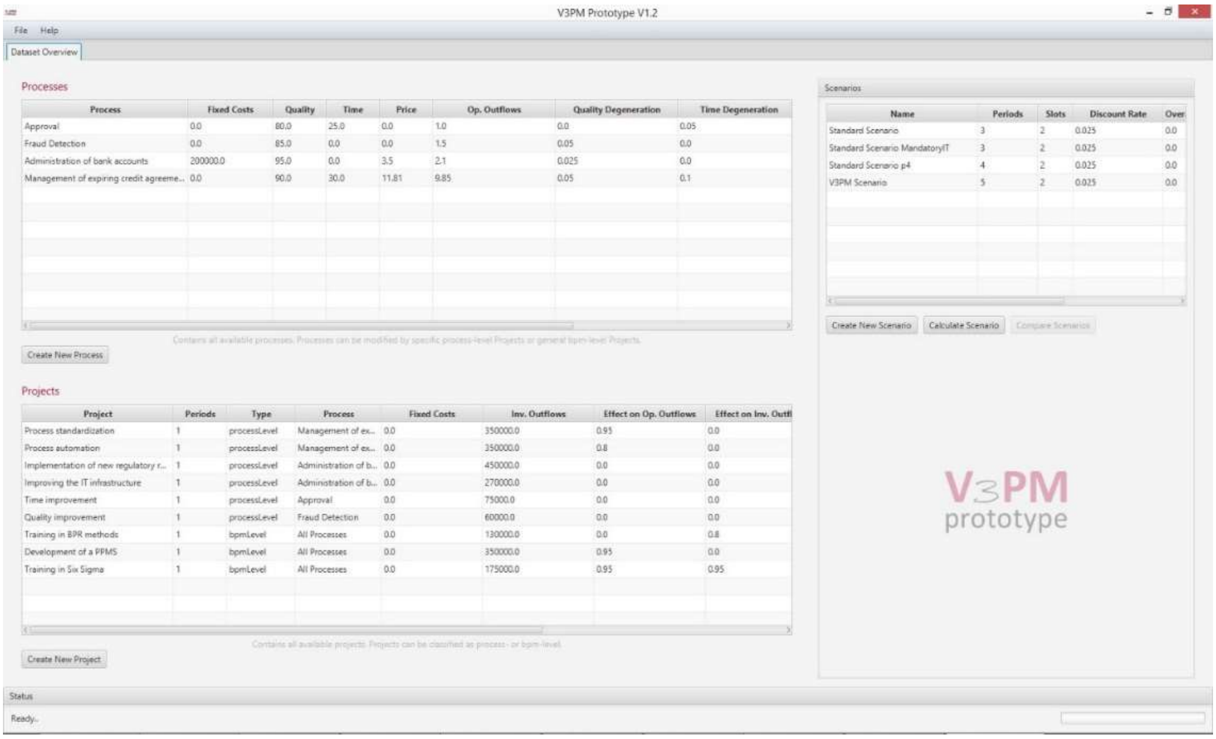

Figure IV.3-5. Start Screen as Overview

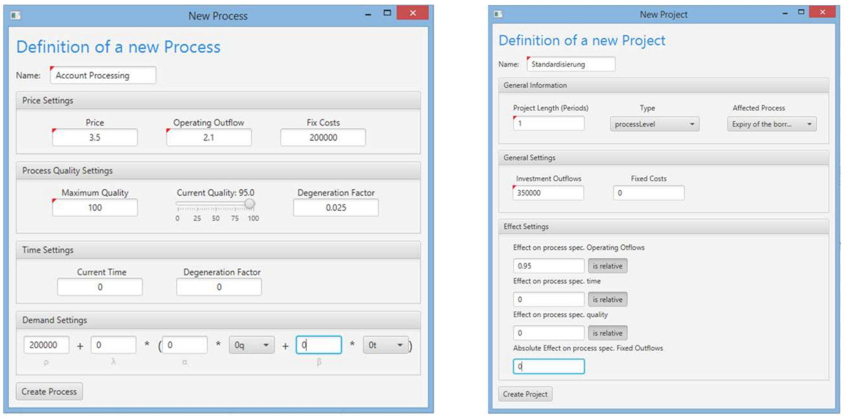

Figure IV.3-6. Definition of new processes or projects

IV.3.3.2 Analysis functionality

Once calculated, the V3PM tool provides detailed information about a scenario. While the back-end design and the GUI mainly support the practical use of the planning model, the analysis section goes beyond the model's intention of determining the optimal BPM roadmap. Beside the visualization of the NPV calculation it enables to gain in-depth insights into the BPM roadmaps associated with a distinct scenario. According to the DSR evaluation criteria (Sonnenberg and vom Brocke, 2012) and with regard to well-informed decisions, this section extends our prior research providing comparisons between roadmaps and scenarios as well as sensitivity analyses to test the robustness of the calculated results.

For each scenario analysis, the results of the respective optimal BPM roadmap are the starting point (Figure IV.3-7). An overview shows information about the scheduled project selection, the processes' performance, the considered interactions and constraints as well as occurred violations while roadmap generation, just as the cash flow development. For better understanding, we choose different presentation forms and chart types. For example, the temporal development of the processes' performance in terms of time, quality, operating outflows, and fixed outflows due to the implementation of projects is presented with line charts. The amount of restriction violations, in turn, is better reflected by a bar chart. Further, the overview includes a project-to-process relationship graph. It captures all interdependencies among processes and projects visually and can be examined interactively by the tool user. Concerning any other admissible roadmap, a list sorted by NPV in descending order allows access to the presented information. In addition, the scenario analysis is the entry for the comparison and sensitivity features.

Figure IV.3-7. Scenario analysis section

The comparison section contains information about roadmaps themselves in terms of the selected projects and their order, about the performance parameters as well as the cash flow development. It represents the differences using selected graphic representations, as well. Comparisons are possible both between roadmaps and scenarios. For roadmaps, the user can compare any of the calculated admissible roadmaps. The scenario comparison considers the best roadmaps of the two selected scenarios and allows for variations in the process, project, and constraint sets. Therefore, it also provides information about the differences regarding the constraint violations. As the project selection just as the effects on time, quality, costs, and cash flows are visible, the comparison section helps to easily detect the impacts of various planning foundations (e.g., a change of a project's position or varying budget targets) on the probable results in terms of intentional variations.

The sensitivity analyses examine the consequences of random, unintentional variations in terms of estimation errors, as the planning model at hand is very complex. The model's robustness should avoid a situation where minor deviations would have major impact on the dominant BPM roadmap. Therefore, we integrated a robustness check to test how strongly the value contribution of the selected roadmap is affected by such variations. For the maximum 50,000 best BPM roadmaps, we vary all project-related input parameters ceteris paribus in a range of ±2% by steps of 1% and determine the percentage of cases in which the optimal BPM roadmap remains dominant compared to the other BPM roadmaps. Following the demonstration examples relying on discussions with our industry partners from the financial service industry (e.g., as described in Linhart et al., 2015), the robustness check confirmed that the calculated optimal BPM roadmap is robust in regard to estimation errors.

Furthermore, the tool user may also refer to a project's input parameter in all or any input parameter whether or not it depends to a process, a project, or the general setting to test the model's robustness. He or she can define a finite interval as variation scope as well as the step width. Allowing for individual and flexible analyses, the user can specify relative or absolute adjustments and decide for positive, negative, or positive and negative interval boundaries in addition. For example, a step width of 5% and a positive boundary of 10% would result in two calculations, while in the first iteration the input value of the selected parameter is increased by 5% and in the second iteration by 10%. With this more detailed sensitivity analysis, the V3PM tool provides further insights to the major factors of influence from two perspectives. The user can investigate the role of a distinct project or the role of a project's specific input parameter in relation to the NPV of an entire roadmap.

IV.3.4 V3PM Evaluation & Discussion

We introduced the V3PM tool to facilitate process managers for calculating scenarios of non-trivial complexity in a multi-project, multi-process and multi-period perspective on process improvement as well as on BPM capability development. We aimed to design a useful and easy-to-use decision support tool that effectively and efficiently calculates the NPV of quite a lot of BPM roadmaps derived from different scenarios. Besides the identification of the optimal BPM roadmap, we intended to use the tool and the results for analysis purposes. This could be realized by a 3-tier architecture with focus on a dynamic, information-rich GUI, appropriate back-end algorithms, and the use of a DBMS.

First performance tests on regular work stations using artificial as well as real-world data already indicate the applicability of the tool in business environments. For example, the roadmap generation and NPV calculation of a case with four processes, nine projects and a planning horizon of five periods requires about half a minute. The robustness check takes about 3 minutes. Complexity drivers are the planning horizon and the amount of available projects. As planning horizons usually are rather small (i.e., between 2 and 8 according to our experiences) and only a limited selection of projects comply with organizational goals (Archer and Ghasemzadeh, 1999), both factors are uncritical. However, more information has to be gathered by real world application. For this, the GUI concept and the analysis functionalities were relevant and necessary steps as well as for the evaluation of our DSR artefact (EVAL3, EVAL4) in the sense of Sonnenberg and vom Brocke (2012).

Besides the limitations grounded in the planning models (Lehnert et al., 2014; Linhart et al., 2015) as conceptual basis of the V3PM tool (e.g. projects that already started in an organization are excluded), there are still shortcomings towards the software quality (ISO/IEC 25010). We will consider further requirements of ISO/IEC 25010 (e.g. introducing a user concept for security reasons) when extending the functionalities to integrate additional aspect from our prior research. However, the V3PM tool was designed for evaluation purposes. Although we already discussed our results with organizations and could derive real world data as input, the V3PM tool is not yet operational in organizations. For instance, we have not yet tested the user interface with intended users. Thus, the V3PM tool needs further development to mature to a full-featured version for decision support in daily business operations. In addition, a comprehensive user documentation and a web-based, platform-independent tool are in preparation.

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V Conclusion and Future Directions

Based on the gap concerning the applicability of scientifically sound process improvement approaches (van der Aalst et al. 2016), this dissertation contributes to the field of business process management (BPM) at the interface of process- and BPM-related issues with a particular focus on process monitoring and control, process improvement and innovation, as well as process program and project management. Chapter V summarizes the new key findings on the identification of critical processes (Research Paper 1), the derivation of redesign ideas (Research Paper 2, 3, and 4), and the planning of redesign projects in view of an organization's strategy (Research Papers 5, 6, and 7) in Section V.1. Further, it represents directions for future research in Section V.2.

V.1 Conclusion

In order to prevent processes' performance from degeneration and to benefit from opportunity-rich business environments, this dissertation addresses three challenges, i.e., (i) the identification of processes that require redesign, (ii) the development and evaluation of new process designs, and (iii) the management of redesign projects from a multi-process, multi-project, and multi-period perspective. Focusing on the two important BPM capability factors *methods* and *information technology (IT)* (Rosemann and vom Brocke 2015), this dissertation extends the BPM body of knowledge around the management of process- and BPM-related issues of the BPM lifecycle that are associated with the most value-creating redesign activity (van der Aalst 2013) along the sequence from process monitoring and control to the planning of concrete redesign measures to overcome the challenges. Thereby, this dissertation provides insights for research and practice.

Before process redesign starts, processes periodically need a thorough and resource-intense analysis (referred to as in-depth analysis). As a first answer, Chapter II presents methodological support for a reasonable scheduling of in-depth analyses that extends the process monitoring and control phase of the BPM lifecycle following decision theory and managerial finance. Thereby, Section II.1 draws parallels to the car industry where cars require general inspection from time to time due to technical reasons and introduces the critical process instance method (CPIM) that analytically predicts after which number of executed instances a process should undergo the next in-depth analysis (Objective II.1) from an economic perspective. The CPIM builds on knowledge from process performance management, value-based BPM, and stochastic processes. It uses process cash flows as performance indicators and extends prior work while using stochastic processes to predict the risky performance of future process instances similar to the assessment of risky price movements as method of mathematical finance. Thereby, the CPIM uses historical performance data and information about the underlying process model to consider two types of performance variation, i.e., variation induced by the paths and tasks included in process models and variation induced by positive or negative deviance experienced during past executions. In doing so, the CPIM does not only focus on the processes' downside risk but also takes the opportunity to achieve further benefits (e.g., by resource reallocations or first mover advantages). As a similarity analysis revealed, process managers particularly have to define the performance benchmark, the thresholds, and the confidence level with special care owing to their strong effect on the prediction. Finally, the CPIM helps rank processes based on their need for in-depth analysis. Its integration into continuous manual or automated process monitoring and controlling activities additionally ensures an iterative, recurrent approach that continuously adjust the identification of critical processes.

Besides the problem-oriented thinking to identify critical processes from an inside-out perspective, BPM also needs methods that facilitate the development of problem-solving strategies from an outside-in perspective. Therefore, Chapter III develops different frameworks, models, and methods that deal with the derivation of new process designs to improve the performance of the current business operations and to enable innovations according to the so-called ambidextrous BPM. In order to develop method and IT capabilities, this chapter draws from innovation management, problem solving, governance choice, value-based management (VBM) as well as computational intelligence and contributes to the body of knowledge on open (process) innovation and computational process redesign. As a first result, Section III.1 presents an Open Innovation Capability Framework (OICF) with 23 capabilities organizations should consider when engaging in OI (Objective III.1) to incorporate external knowledge to increase their innovation potential. Section III.2, then, focuses one of the associated capabilities, i.e., OI decision-making, and extends the theoretical reasoning for when and why certain forms of governance are suitable in the context of open process innovation (OPI) (Objective III.2). Finally, Section III.3 combines the inside-out and outside-in perspectives and introduces an evolutionary algorithm (EA) as integrated approach to derive process improvement and innovation while keeping well-performing design structures on an incremental and continuous basis (Objective III.3).

The OICF in Section III.1 is the first framework that takes a holistic perspective on OI capabilities. It integrates and extends the scope of existing OI-related capability frameworks derived from mature but isolated OI research streams as well as from the feedback of OI experts from academia and industry. As both BPM and OI are dynamic capabilities, the OICF follows the domain-independent, holistic perspective of Rosemann and vom Brocke (2015) and groups the 23 resulting OI capabilities into the factors strategic alignment, governance, methods, information technology, people, and culture. Overall, the OICF helps to define the scope of OI initiatives and to gain insights into the current state of the art on OI capabilities. As major results from a strategic perspective, even though organizations have to promote openness, the effort concerning search breadth (i.e., the number of external sources and channels involved in OI) and search depth (i.e., the intensity of single collaborations) must not exceed their benefit. Further, the search characteristics in terms of an OI strategy also have to fit to the overall business and IT strategies according to the entire bandwidth from a market defender to an opportunity-seeking prospector. Search breadth and search depth, then, are implemented by an appropriate governance. Particularly, OI decision-making capabilities are necessary to decide when to use specific open (e.g., partnerships, innovation contests, communities) or closed forms of innovation (e.g., authority-based, consensus-based hierarchy). Besides, the factor *culture* also plays an important role in the selection of an appropriate OI strategy. As none overarching culture exists, organizations carefully have to adopt their OI strategy as well as other factors and capability areas to the innovation behavior of the distinct subcultures in the organizational units. Culture, in turn, is related to the people. These are the driving force behind OI initiatives and require specific but not always necessarily unique capabilities. For example, technology mastery, i.e., the ability to use modern (information) technology, is one of these important capabilities. Concisely, the OICF is a foundation for prioritizing, selecting, and operationalizing capability areas as well as for deriving implementation roadmaps to balance the distinct strategic, operational, and cultural implications of OI.

In addition to the more holistic view of Section III.1 on OI in general, Section III.2 takes a more specific view on OPI as integrated management perspective on OI and BPM. It addresses the specific challenges of OPI problems resulting from the process at hand and focuses with OI decision-making on one of the essential OI capabilities derived from Section III.1. Drawing from the knowledge on OI governance choice and BPM collaboration, Section III.2 establishes a research model of OPI-related governance choice that provides further insights into the requirements of an appropriate governance for OPI initiative management. The research model links process complexity and hidden knowledge to the performance of OPI initiatives in terms of efficiency and effectiveness. As the hidden knowledge and the process complexity are mainly driven by contextual factors, they cannot easily be influenced at the time of need for innovation or at all. In answer to this, the research model reveals the potential of an innovation-friendly organizational environment and culture to decrease hidden knowledge in advance as new insight and confirms the importance of project selection and management at the process level (cf. Linhart et al. 2015) as part of OI decision-making. To extend the theoretical reasoning for when and why certain forms of governance are suitable for OPI, Section III.2, then, deduces four distinct characteristics, i.e., expertise, integration, size, and binding, which in combination cover all concrete governance forms. Each of these characteristics leverages the innovation performance in a different manner and results in a tradeoff of simultaneously positive and negative effects of governance choice. To sum up, the uncovering of this tradeoff contributes to the understanding of an appropriate governance choice for OPI. It provides valuable insights to make use of different stakeholders' distinct strengths on the way to process innovations and to estimate the cost-benefit relationship of such initiatives more precisely. Nevertheless, the presented interrelationships were deduced on a theoretical basis and, therefore, the research model has to be investigated empirically.

Whereas OI or OPI do not necessarily depend on existing process designs, new innovative process designs could also be derived by process improvement approaches that build on the status quo design and keep well-performing design structures. Following this, the EA in Section III.3 incrementally develops new process designs. Thereby, the algorithm provides computational support in answer to the ever increasing real-world problem complexity in today's business environment that exceeds the cognitive capacity of human beings and provides an objective basis for further discussions in a redesign committee. With its similarity to the BPM lifecycle on a conceptual level, the algorithm mimics the cognitive approach of human decision-makers but avoids the disadvantages of subjective vagueness and personal biases. On the implementation level, the algorithm considers all key process elements (i.e., activities, resources, and their logical connections), ensures feasible designs that produce the desired process output by a repair mechanism, and identifies the most valuable designs based on a valuation function from value-based management (VBM). As one of its major contributions, the algorithm even allows for decision points based on process attributes to guide the process flow resulting in more realistic process designs applicable in real-world scenarios. Its applicability, correctness, and performance was demonstrated in a simple and a complex setting in terms of the number of activities that also confirmed the algorithm's superiority to competing artefacts concerning scope and efficiency. Briefly, the algorithm provides promising design candidates in an acceptable time and a clear prioritization of designs instead of a set of not-dominated designs.

However, the implementation of a new process design is only one of many process improvement opportunities. Therefore, Chapter IV proposes different decision models that support the strategic planning of redesign projects within organizations and that contribute to the body of prescriptive knowledge on process improvement and process decision-making. Section IV.1 and IV.2 helps determine optimal process improvement roadmaps in line with the principles of project portfolio selection and VBM. A process improvement roadmap is a set of improvement projects scheduled to multiple planning periods, each of which enhances the performance of the process in focus. Among possible improvement roadmaps, the decision models recommend selecting the improvement roadmap with the highest value contribution in terms of the roadmap's expected (risk-adjusted) net present value (NPV). Whereas Section IV.1 focuses on process characteristics that reflect how work is performed and organized from a more holistic view (Objective IV.1), Section IV.2 addresses the question how to economically reasonably combine projects for different flexibility types to cope with demand uncertainty and variety in the service industry (Objective IV.2). Both decision models were developed in line with the design science research (DSR) paradigm (Gregor and Hevner 2013).

The decision model of Section IV.1 particularly differs from and extends existing single-/multi-process improvement approaches by not only focusing on process performance (e.g., time, quality, and costs), but by especially accounting for the underlying process characteristics (e.g., number of process variants, fraction of non-routine instances, fraction of instances handled externally, degree of automation, and automation potential) inspired by established industrialization strategies, i.e., automation, sourcing, standardization, and flexibility. Thereby, the decision model allows for any combination of industrialization strategies within one project. Further, the decision model also accounts for selected constraints (e.g., predecessor/successor, restricted budgets) and considers deterministic, scheduling, intra-, and inter-temporal interactions. Interactions among the industrialization strategies are covered via the investment outflows of process improvement projects, a means also used to incorporate interactions among projects. Interactions among projects are also covered via multiplicative and additive effects on performance indicators, which are cascaded over time. As a result, the decision model allows for a more detailed planning and is closer to reality compared to existing approaches.

Against the increasing importance of flexible service processes, the decision model of Section IV.2 investigates the achievement of an appropriate level of flexibility. The decision model covers a single service process and focuses on how this process performs regarding the performance indicators, i.e., time, flexibility, and costs. The flexibility projects refer to volume or functional flexibility and differently affect a service provider's capacity configuration (i.e., internal, external, dedicated, and flexible) as well as the performance of the service process under consideration. In order to reflect the high demand uncertainty of the service industry, the decision model, further, accounts for different request types (i.e., runners, repeaters, and strangers) and risky demand as one of the most important flexibility drivers. The value contribution of a flexibility roadmap, then, is based on the expected value of its stochastic NPV using a risk-adjusted interest rate for discounting. In doing so, the decision model considers all cash effects that result from volume and functional flexibility projects as well as from service delivery.

For evaluation purposes, both Sections IV.1 and IV.2 followed the framework proposed by Sonnenberg and vom Brocke (2012). The decision models as DSR artefacts were evaluated using feature comparison, prototype construction, and demonstration examples in order to fulfil the requirements of the evaluation activities EVAL1 to EVAL3. For the decision model of Section IV.1, the results were also discussed with a group of experts. For the decision model of Section IV.2, an additional extensive scenario analysis was conducted to test the model's robustness and to get a deeper understanding toward the projects' effects and the inter- and intra-temporal interactions. However, with regard to scientific rigour and practical applicability, case studies would benefit from a software tool that extends the prototypes of Section IV.1 and IV.2. Therefore, Section IV.3 presents a useful and easy-to-use decision support tool, the Value Based Process Project Portfolio Management (V3PM) tool, to facilitate process managers for calculating scenarios of non-trivial complexity from a multi-project, multi-process and multi-period perspective on process improvement as well as on BPM capability development in an integrated manner. The V3PM tool is an executable, standalone program that effectively and efficiently generates all admissible project roadmaps, applies the objective function to each admissible roadmap to calculate the NPV, and selects the roadmap with the highest NPV. With a new 3-tier architecture, modified back-end algorithms, and a dynamic, information rich graphical user interface, the V3PM tool overcomes the shortcomings and bottlenecks, particularly the performance issues, of the existing prototypes. A scenario concept that allows to examine different persistent problem sets based on the combinations of projects and processes simplifies data in- and output and prevents errors. Additional in-depth insights in terms of sensitivity analyses improve the decision support. Concerning DSR, the V3PM tool can be used both for incorporating a proof of concept (EVAL3) and for preparing an application in naturalistic settings to validate its usefulness (EVAL4). All in all, the V3PM tool at its current stage is a first step towards a full-featured decision support tool applicable in daily business operations.

To summarize all of these findings, this dissertation provides methodological and computational support to the BPM phases process monitoring and control, process improvement and innovation, as well as process program and project management. Thereby, it draws from knowledge of other disciplines (e.g., idea generation from innovation management, computational intelligence from information systems research, VBM from management science). With conceptual as well as design-oriented approaches and a distinct focus on processes instead of process models, this dissertation contributes to the applicability of scientifically sound process improvement approaches. The provided frameworks, models, and methods particularly extend the existing BPM body of knowledge by economic aspects and extends the quantitative toolset while reducing the bias by subjective vagueness. In doing so, this dissertation supports the prioritizing, selecting, and operationalizing of process improvement and innovation activities in line with an organization's goals.

V.2 Future Prospects

Bridging the gap between BPM in academia and industry is a stepwise process. Even though this dissertation contributes to the further development of BPM, especially in the context of process improvement and innovation, there remain limitations and challenges, which direct future research. Thereby, it is of particular importance to consider two perspectives (Schmiedel and vom Brocke 2015): On the one hand, BPM could act itself as a driver of innovation while improving business processes. On the other hand, there are further opportunities to innovate BPM as discipline.

As to the first perspective: The scientifically sound process improvement approaches have to deal with the tradeoff between being realistic and easy-to-use at the same time. As these requirements raise the complexity towards a model's or method's construction and calculation, assumptions, abstractions, or restrictions help simplify the problem at hand in a first step. Then, further research must continue on that in a second and all following steps. In this dissertation, the single view on distinct aspects (e.g., projects, processes, and process instances) is one major issue. The single-process perspective of Section IV.1 and IV.2 neglects the implementation of multiple projects per period as well as portfolios of interacting processes. In reality, depending on capacity restrictions, organizations are usually able to implement more than one project simultaneously. In doing so, the decision models would also have to cater for intra-temporal interactions between projects (e.g., budget restrictions, mandatory projects, and input-output-interactions) in addition to the inter-temporal interactions. At least, the V3PM tool (Section IV.3) is prepared for multiple projects per period focusing on multiple processes. Nevertheless, further insights toward a multi-process perspective (e.g., in the context of flexible service processes) would help the BPM discipline mature at the intersection to project portfolio management and performance management. Regarding the process portfolios, the Sections II.1, III.3, IV.1, and IV.2 have in common to analyse each process individually and, thus, consequently neglect interdependencies between these processes. For the inter-process dependencies between interconnected processes (Letmathe et al. 2013), business process architectures and process model repositories already provide structured descriptive overviews (Dijkman et al. 2016; Malinova et al. 2015). However, only one approach uses this information to derive a network adjusted key performance indicator showing the need for improvement of a process in a network (Lehnert et al. 2015). Thus, the critical number of instances derived by the CPIM (Section II.1), the incremental development of new process designs (Section III.3), as well as the selection and scheduling of improvement projects (Sections IV.1 and IV.2) should also be extended by the interactions among processes. In addition, BPM approaches should cater for intra-process dependencies between process instances. At least, Letmathe et al. (2013) takes them into account for developing a capacity planning model and Conforti et al. (2016) develop a process instance graph to share risk information across multiple process instances for the predictive monitoring and early detection of risks. Nevertheless, for the identification of critical processes, techniques from time series analysis (e.g., autocorrelation, asymmetric effects) could help to overcome the CPIM's weakness of independent process instances.

A particular form of simplifications is the neglect of organizational context that would provide the ability to shape more specific solutions compared to holistic approaches. Therefore, the distinct BPM approaches, methods, and models should be more sensitive toward a broader variety of business context (vom Brocke et al. 2015). This is another major issue in the BPM body of knowledge (vom Brocke et al. 2015) generally and still lacks in this dissertation as well. At least, Section III.2 investigates the role of context for OPI and Sections IV.2 presents a decision model designed for the distinct requirements of the service industry. However, the results of the Sections II.1, III.1, and IV.1 would also benefit from the consideration of contextual factors. In Section II.1, the CPIM is based on performance data and neglects external events that may influence the scheduling of the next in-depth analysis. As complex event processing systems already account for such events (Krumeich et al. 2015), a combination of both approaches could overcome CPIM's drawback. Moreover, CPIM takes all process variants of a process into account. However, an increasing number of process variants influences the CPIM owing to an increasing variance of the instance cash flows and makes in-depth analyses impossible. Therefore, it might help to cluster similar process variants to limit the set of executed instances. To compare process variants, process matching techniques and trace clustering in process mining provide valuable insights (Beheshti et al. 2016; Song et al. 2009). In Section III.1, the OICF provides a holistic overview of capabilities relevant to engage in OI. Nevertheless, not every organization needs to develop each capability due to contextual factors. Therefore, different capability profiles might be required. First approaches exist (Gassmann 2006; Hung and Chou 2013; Schweitzer et al. 2011; van de Vrande et al. 2009), but are limited to distinct capabilities as well as distinct context factors. Therefore, future research should strengthen and extend the insights toward the role of context on open innovation, reflecting both internal (e.g., size) and external (e.g., industry, environmental turbulence) characteristics (Huizingh 2011). As the decision model in Section IV.1 abstracts from specific application domains as well, future research should work on domain-specific sets of process characteristics along the same line of reasoning.

In addition to – and partly derived from – the simplifications, the insights of this dissertation would benefit from further operationalization as well as from further evaluation, particularly real-world case studies, to prove usefulness and applicability. As the OICF in Section II.1 does not cater for a meaningful sequence of capability development, specific OI capability maturity models could guide organizations in the future, analogous to the development of general BPM capabilities (Forstner et al. 2014; Rosemann and vom Brocke 2015). For the methods and models provided in the Sections II.1, III.3, IV.1, and IV.2, in turn, a long-term vision should focus on the stepwise expansion of the current prototypes to mature to full-featured decision support in daily business operations. Thereby, it is reasonable to hide the complex interdependencies by computational support. As a first step, Section IV.3 already extends the artefacts of the Sections IV.1 and IV.2, particularly by a simple user interface as well as sophisticated visualisation and analysis functionalities that are still missing for the application of the EA in Section III.3. Nevertheless, also the V3PM tool proposed in Section IV.3 still lacks quality and further software requirements (e.g., a user concept for security reasons). Besides, even though the distinct results were discussed with industry experts and real world data acted as input for the evaluation, the method and tools are not yet operational in organizations. The usefulness for organizational stakeholders can only be achieved in detail by extensive software tests with the intended users. This applies both to the user interface as well as the determination of input parameters (e.g., cash flows on the single process level). Ultimately, the effort to get the input parameters for decision models must not exceed the benefit of the calculated results. In doing so, potential shortcomings in case of missing process design elements (Section III.3), the equally distributed demand on distinct process variants (Section IV.1), and the periodic-independent, static project effects (Section IV.1 and IV.2) could be evaluated at the same time.

As to the second perspective: Further development of the theoretical BPM body of knowledge is necessary to provide new insights. Industry will, then, benefit from the matured BPM discipline in the long-term. This dissertation links BPM to OI, a relatively new but already established paradigm of innovation management (Section III.3). Consequently, the revealed research model would benefit from further first-hand experiences towards the context-specific governance choices as well as further insights into the multidimensional constructs process complexity and organizational complexity. The characteristics included in process complexity (e.g., knowledge-intensity, repetitiveness, creativity) are not mutually exclusive. In addition, the moderating effect of the governance choices on process complexity could differ depending on these characteristics. Regarding the organizational complexity, the mostly nominal distinctive features still raise the question whether an organization should invest in BPM capabilities or OI capabilities, especially since there has only been little research on context-specific OI capabilities. Therefore, a detailed examination of these both multidimensional constructs would be beneficial to academia and practice. Besides, owing to the product innovation-centric research on OI governance, there is only little experience to OPI governance. Thus, empirical studies could help validate the model in general and understand which governance form fits best in distinct situations in particular. The results could be one step further on the solution of the tradeoff concerning the governance forms' effectiveness and efficiency resulting from their four key distinctive features (i.e., expertise, integration, size, and binding). Further research, then, could focus on OPI community portfolios that combine the advantages of distinct governance forms and circumvent their specific disadvantages.

Besides OI, there are further developments that could be adapted to innovate the BPM discipline. Therefore, future directions should not only focus on the further development of the insights derived in this dissertation to realistic and easy-to-use approaches that fill the gap between theory and practice, but also look at current developments regarding digitalization and big data. With the exponential growth of available process information, e.g., gathered by workflow management or BPM systems, computational support for process improvement becomes even more powerful in the future. Computational intelligence will get an increasing advantage over human intelligence owing to the disparity between the cognitive capacity and the problem complexity. Nevertheless, existing data-driven approaches based on process log data only focus on discovery, conformance checking, and enhancement (van der Aalst 2011). They still neglect to learn about processes and their relations based on the plethora of information contained in the process log data to derive smarter approaches (van der Aalst et al. 2016). With Section II.1, this dissertation provides one of only a few approaches that already address the new opportunities of the growing volume of event data for monitoring and controlling processes (Recker and Mendling 2016).

With an increasing computational support and owing to the rapid development of information and communication technology (ICT), the role of humans inter alia as users of these applications will influence future process improvement initiatives in a way that organizations will realign their business goals with respect to social criteria (Calvo and Peters 2014). Positive computing is one new trend in business information systems engineering (Pawlowski et al. 2015). With impact on organizational and process design, positive computing will require new process improvement strategies that consider effects and impacts of changes (e.g., implementing new process designs), that cater for the well-being of the participants, and that develop new key performance indicators, which will go behind the perspectives of the Devil's Quadrangle and VBM as used in this dissertation (Pawlowski et al. 2015).

Finally, this dissertation matures BPM as paradigm of organizational design with a particular focus on process improvement and innovation. The provided frameworks, models, and methods are building blocks towards an integrated BPM lifecycle focusing on (i) the identification of processes that require redesign, (ii) the development and evaluation of new process designs, and (iii) the management of redesign projects from a multi-process, multi-project, and multi-period perspective. Nevertheless, scholars should feel encouraged to drill on the discussed assumptions and limitations and to continue along the future directions to bridge the gap between BPM research and practice.

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