



**Good Decisions and High Business Value –
Descriptive and Normative Contributions to IS Decision-Making**

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Index of Research Papers

This doctoral thesis contains the following research papers:

Research Paper 1 (VHB-JOURQUAL 3: category B)

Afflerbach P (2015) The Business value of IT in light of prospect theory – A new explanation for IT paradoxes.

In: *Business Information Systems Engineering* 57(5):299-310. (DOI 10.1007/212599-015-0400-6)

Research Paper 2 (VHB-JOURQUAL 3: category A):

Afflerbach P, Beer M, Manderscheid J, Neumeier A (2016) The integration of the 5th dimension - A quantitative framework on the business value of big data analytics

Submitted to: *Journal of Management Information Systems*

Research Paper 3 (VHB-JOURQUAL 3: category A):

Afflerbach P, Frank L (2016) Customer experience versus process efficiency: Towards an analytical framework about ambidextrous BPM.

In: *Proceedings of the 37th International Conference on Information Systems (ICIS), Dublin, Ireland, December 2016.*

Research Paper 4 (VHB-JOURQUAL 3: category B):

Afflerbach P, Hohendorf M, Manderscheid J (2016) Design it like darwin - A value-based application of evolutionary algorithms for proper and unambiguous business process redesign.

In: *Information System Frontiers* 19(5) (DOI /10.1007/s10796-016-9715-1)

Research Paper 5 (VHB-JOURQUAL 3: category B):

Afflerbach P, Bolsinger M, Röglinger M (2016) An economic decision model for determining the appropriate level of business process standardization.

In: *Business Research* 9(2):335-375. (DOI: 10.1007/s40685-016-0035-6)

Research Paper 6 (VHB-JOURQUAL 3: category B)

Afflerbach P, Kastner G, Krause F, Röglinger M (2014) The business value of process flexibility - An optimization model and its application in the service sector.

In: *Business Information Systems Engineering* 6(4):203-214. (DOI 10.1007/s12599-014-0333-5).

I Introduction

Digitalization has significantly increased the competitive pressure on organizations. Companies must be able to continuously react on technological innovations as well as to recognize new opportunities of efficiency and competitive advantages. Thus, the ultimate success of surviving the disruptive power of digitalization requires series of correct decisions on IS and fast reactivity towards changes (Meyer et al. 2014; Edwards 1962). A prerequisite of correct IS decision-making is the critical evaluation of both, opportunities and threats with respect to the business value created (Mata et al. 1995, p. 487). For fulfilling this prerequisite, decision-makers have to deal with an enormous decision complexity which arises from two key characteristics of IS: dynamism and innovativeness. Dynamism refers to the high pace of the technological progress which continuously enhances and changes decision alternatives (Henfridsson and Bygstad 2013). Closely related is the innovativeness of IS (Irani and Love 2002). Organization can often not draw from an extensive knowledge base on the new technologies. In these cases, decision-makers need to interfere the actual impact of a technology within the organizational environment from their perceptions and experiences. The general problem with human perception and decision-making however is that it is often based on heuristics and prone to biases (Gilovic et al. 2002). These psychological schemes often lead to perceptive deviations from objective values, which then typically may imply irrational and wrong IS decisions.

Two prominent examples for situations where biased perception may lead to irrational IS decision-making are the productivity paradox and the perception paradox. The productivity paradox covers the empirical observation that economic productivity stagnated in the 1980s, while the number of computers increased more than threefold (Brynjolfsson 1993). The possible explanations for this paradoxically negative influence on productivity can be classified into four categories. First, the high pace of technological progress require more frequent replacement or upgrade investments as compared to classical capital investments. With every adjustment, organizations lose experience and thus productivity (Yorukoglu 1998; David 1991). As a result, overall productivity is smaller than compared to classical capital investments. Second, pioneer studies illustrating the paradoxical effect were shown to suffer from measurement errors. Productivity statistics typically underestimate quality and speed improvements, which are often the main benefits of IS (Brynjolfsson 1993). Thus, total productivity is underestimated by these pioneer studies. Third, investments in IS take place in a competitive environment and may be of a redistributive rather than of a creative

nature. This means that IS may be valuable to only a few organizations but unproductive when considering the entire industry (Brynjolfsson 1993). Fourth, and this is the central approach of this doctoral thesis, the productivity paradox may originate from of wrong IS decisions. The underlying hypothesis is that wrong decisions on IS made the realized business value to fall short from the potential organizational impact.

With considering measurement errors and with applying more sophisticated measures for productivity, a significant number of studies now contradict the paradoxically negative effect of IS on productivity (e.g., Tallon et al. 2001; Gurbaxani et al. 1998). However, biased perceptions and wrong decisions still threaten the business value of IS. Anderson et al. (2003) coined this threat as the new productivity paradox. They illustrate that IS do generate economic returns, but human estimates for these returns tend to be overestimated (Dewan et al. 2007). Biased value perceptions lead to biased decisions, which then may reduce the business value of IS (Anderson et al. 2003).

The perception paradox refers to misperceived sources of IS business value. In general, IS can improve organizational performance by improving efficiency or by establishing competitive advantages (Melville et al. 2004). Highly valuable IS are mainly associated with competitive advantages in terms of improvements in customer satisfaction, product and service quality (Papp 1999). However, practitioners perceive these effects of IS only partially and evaluate cost-reducing effects higher (Henderson and Venkatraman 1993; Papp 1999). The possible explanations for this misperception can be divided into two categories. First, competitive advantages are typically intangible and more difficult to quantify as compared to cost-reduction, demotivating managers from making such revenue investments (Papp 1999). Second, competitive effects of IS are typically more risky than operational investments. This is because competitive advantages realize business value in the interplay with market and environmental factors. As these factors underlie additional uncertainty, the risk of the business value is typically higher. Finally, the perception paradox may lead decision-makers to choose less valuable cost investments and neglect more valuable revenue investments. Again, biased decision-making towards less valuable types of IS can decrease the potential business value which IS can really have for organizations. The main objective of this doctoral thesis is to help practical decision-makers to identify situations where such biases may originate and to provide a suitable tool-kit for assisting in these complex decision situations of IS.

Decision Theory and IS Decision Problems

For pursuing this overarching research objective, this thesis applies methods from decision theory to IS decision problems. In general, decision theory splits up into two streams: descriptive or positive decision theory and normative or prescriptive decision theory. Whereas descriptive theories describe how individuals do decide, normative theories investigate how they should decide (MacCrimmon, 1968). As for the normative stream, academia proposes rational procedures and assumes a rational decision-makers with infinite cognitive abilities – the “homo oeconomicus” (Dinev et al. 2015). In contrast, the descriptive stream takes a psychological perspective on decisions and determines where human beings deviate from the axioms of rationality to develop methods for debiasing (Bell et al. 1988).

The decision problems of IS can be structured along the organizational architecture from Buhl and Kaiser (2008). Thereby, this doctoral thesis uses a comprehensive understanding of the term IS inspired by Buhl and Kaiser (2008) and Falkenberg et al. (1998) as an organizational sub-system for dealing with information. As such a sub-system, IS comprise the 4 layers of the organizational architecture as per Buhl and Kaiser (2008): customers or business model, business processes, applications and infrastructure. In this doctoral thesis, we aggregate the two technical layers to the term IT. Business models are blue-prints or concepts that explains how an organization create value for its customers (see. e.g. Casadesus-Masanell and Ricart 2010; Demil and Lecocq 2010; Morris et al. 2005; Laudien and Daxböck 2015; Zott and Amit 2010, 2013). Business processes are a collection of events, activities, and decision points whose interplay collectively leads to an outcome (Dumas et al. 2013). Thereby, business processes compile business models into operational procedures that enable an organization to deliver valuable outputs as prescribed by the business model. Finally, IT covers technological components like enterprise architectures, software applications, and infrastructure components (Kohli and Grover 2008). Hence IT is the technological backbone that allows processes and business models to work in the intended way.

It is important to note that this doctoral thesis understands IT as the technological part of IS. IS additionally cover business processes and business model components that are related to the usage of IT. Following the basic idea of the organizational architecture, IS are an interplay of business model, business processes and IT. As illustrated by figure 1, this interplay can be interpreted from two perspectives. The align-perspectives reads the

architecture downwards and emphasizes that processes and IT have to support the organizations business model. The enable perspective reads from the IT layer upwards and illustrates that IT can enable new business models, if the business processes support the innovation appropriately. Applied on the challenges of digitalization, the logic of the architecture shows that correct IS decisions are required on all three layers to generate high business value. Thus, knowledge from prescriptive and descriptive decision theory is needed.

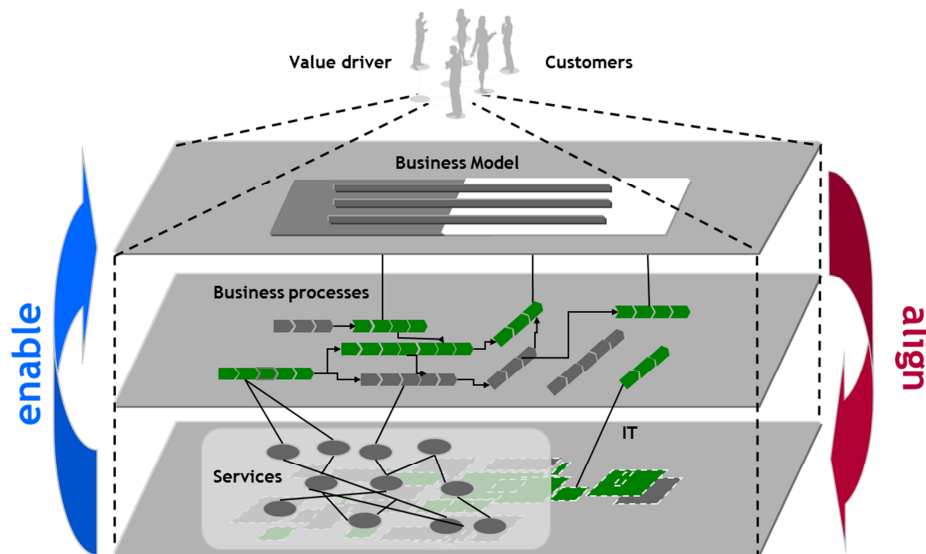


Figure 1: Organizational Architecture inspired by Buhl and Kaiser (2008) p. 47

The Special Role of Business Processes

As intermediate layer between IT and business models, business processes take a special role in IS decision-making. Whether decision-makers want to set up a new business model on the back of new IT innovations (enable perspective) or whether market and technological changes disrupt the requirements of the current business model (align perspective), business processes need to get redesigned to respond to these changes (Doomun and Vunka Jungum 2008). This continuous redesign pressure is also why process redesign is often considered as the most value-creating activity of business process management (BPM) (Dumas et al. 2013; Zellner 2011). In general, redesign decisions can be structured into three activities along the “process of redesign” from Limam Mansar et al. (2008): Setting strategic objectives, derivation of redesign candidates, and implementation (Limam Mansar et al. 2008). Setting strategic objectives refers to setting the evaluation frame and aim to ensure that the redesigned process corresponds to associated decisions on the other layers. Derivation of redesign candidates covers the identification and evaluation of ideas about how to create a superior process in terms of the predefined strategic objectives (Limam Mansar and Reijers

2007). Implementation is rather operational and means to put the chosen redesign into practice.

Due to the high complexity and the high impact of process redesign, extensions of the scientific and practical tool-kit for supporting redesign decisions are still in high demand (van der Aalst 2013). Although there already exists a broad range of mature tools (Harmon and Wolf 2014; van der Aalst 2013; Vanwersch et al. 2016), most redesign approaches are qualitative and rely on human intuition (Hofacker and Vetschera 2001). As prescriptive decision theory suggests, these creative approaches can suffer from limited cognitive capacities of human decision-makers, biased decision-making and neglections of viable alternatives. Therefore, practical decision-makers are in deep need for rational procedures that support them in their decisions (Sharp and McDermott 2008; Zellner 2011). Furthermore, practitioners also require descriptive results on how human decision behavior can be made more rational. From a scientific perspective, many scholars also emphasize the relevance of this research topic and especially denote the lack of computational redesign support as an important and current research gap (van der Aalst 2013; Vergidis et al. 2008; Zellner 2011).

Descriptive knowledge on human irrationalities in IS decisions and the deep need for normative decision procedures make up the research field of IS decision theory. Figure 2 illustrates that the problem domain of business models, business processes and IT as well as the research streams of normative and descriptive decision theory as solution domains span up the research context. Further contributions in this field are of high practical and academic relevance as they promise to increase the generated business value of IS.

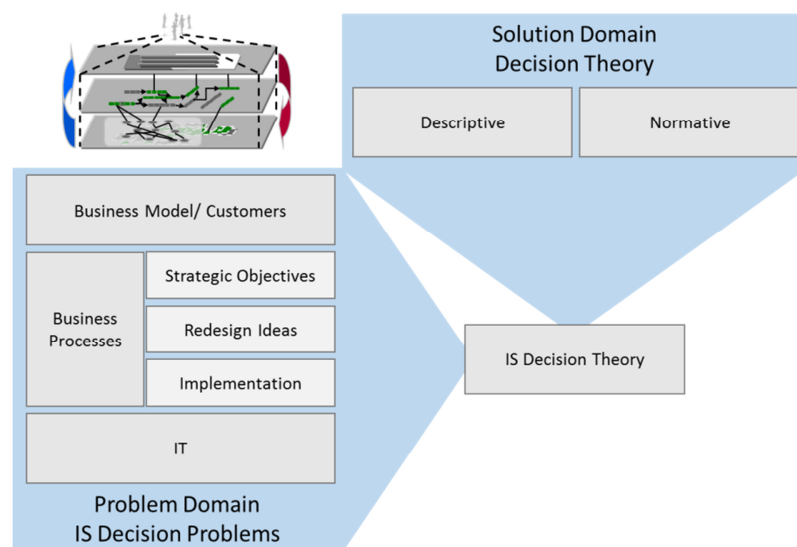


Figure 1: IS Decision Theory

I.1 Objectives and Structure of this Doctoral Thesis

The main objective of this doctoral thesis is to contribute to the field of IS decision theory. Thereby, it has a strong focus on the problem domain of business processes given its high relevance as intermediate layer of the organizational architecture. The Table 1 gives an overview of the pursued objectives and the structure of the doctoral thesis.

I Introduction	
Objective I.1:	Outlining the objectives and the structure of the doctoral thesis.
Objective I.2:	Embedding the included research papers into the context of the doctoral thesis and formulating the fundamental research questions.
II Descriptive IS Decision Theory – Investigating Paradoxes Inherent to the Business Value of IT (Research Papers 1)	
Objective II:	Explaining the productivity paradox and the perception paradox with prospect theory and deriving retaliatory actions
III Normative Guidance on IT Decisions – How to Evaluate Investments in Big Data Analytics (Research Papers 2)	
Objective III	Providing a practical framework on the business value of big data analytics considering the technological characteristics of volume, variety, velocity, and veracity
IV Normative Guidance on Strategic Redesign Decisions (Research Papers 2 and 3)	
Objective IV.1:	Providing a structured approach for choosing correct redesign objectives under explicit consideration of customer needs
Objective IV.2:	Providing a computational tool for creating process redesign ideas
V Normative Guidance on Operational Redesign Decisions	
Objective V.1:	Providing decision support on business process standardization
Objective V.2:	Providing decision support on business process flexibilization
VI Results and Future Research	
Objective VI.1:	Presenting the key findings of the doctoral thesis
Objective VI.2:	Identifying and highlighting areas for future research

Table 1: Research Objectives

I.2 Research Context and Research Questions

In the following section, the research papers included in this doctoral thesis are embedded in the research context with respect to the above stated objectives.

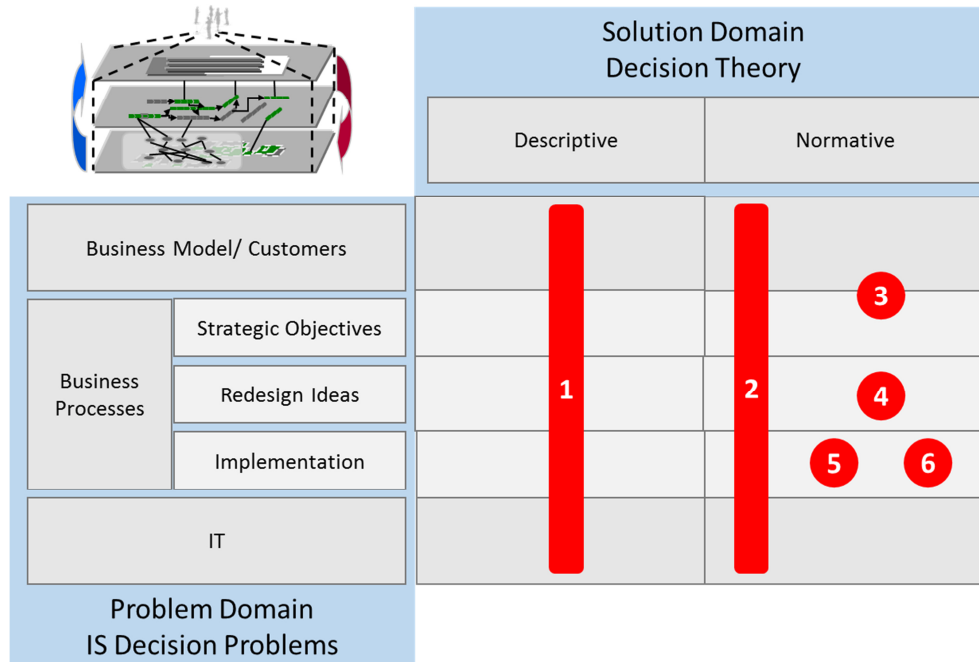


Figure 3: Research papers embedded in research context

In order to provide ideal conditions for good IS decisions, an organization needs to implement a suitable tool-kit for supporting practical decision-makers, while still allowing for sufficient room for creativity (Limam Mansar et al. 2008). Whereas the blind trust in computational decision-tools will often oversee creative solutions, the reliance on the experiences and intuitions of decision-makers may be associated with biased choices or even the neglect of viable alternatives. Thus, IS decision-making should always draw from descriptive as well as prescriptive decision theories and consider the multiple problem domains. Figure 3 embeds the research papers of the doctoral thesis in the research context of IS decision making. Chapter II takes the descriptive perspective and utilizes prospect theory as “gold standard” for human decision behavior to derive additional explanations for the questions about why and under what conditions the presented paradoxes occur. It is important to note that research paper 1 emphasizes the roles and meanings of the paradoxes in the research stream dedicated to the business value of IT (BVIT). Although, the name of the research stream implies a focus on IT as the technical part of IS, BVIT is defined as the *organizational* performance impacts of IT at both the intermediate *process* level and the

organization wide level” (Melville et al. 2004, p. 287). Thereby, research paper 1 does not focus on the technical level of IS but on the whole organizational architecture of IS.

Chapter III takes the normative perspective on IS and demonstrates the usefulness of prescriptive procedures for managing the complexity of IS decisions on new, innovative technologies for the example of Big data analytics (research paper 2). Aiming to quantify the business value of the technology, research paper 2 also address the whole organizational architecture of IS. Chapters IV and V narrow the normative perspective on the process of redesign. Whereas chapter IV focuses on strategic decisions of setting redesign objectives (research paper 3) and generating new redesign ideas (research paper 4), chapter V deals with operational decisions on evaluating business process standardization (research paper 5) and flexibility (research paper 6) as two key aspects of redesign.

I.2.1 Chapter II: Descriptive IS Decision Theory – Investigating Paradoxes Inherent to the Business Value of IT

Research Paper 1:

The Perceived Value of IT - A New Conceptual Framework for the Business Value of IT

In its origins IT (in the definition of the research paper and IS in the understanding of the doctoral thesis) was expected to become the “biggest technological revolution men have known” (Snow 1966 p. 650). Rather than meeting these high expectations, IT aroused great disillusionments in the 1980s, when economic productivity stagnated, although the number of computers increased significantly (Brynjolfsson 1993). Soon academia supports this disillusionment, when first studies could not verify a significant business value of IT (BVIT) (Yorukoglu 1998). Responding to the doubts on the BVIT, the IS research community formed a new research stream around this central topic and indeed the scientific efforts paid out (Kohli and Grover 2008). Today, the existence of the BVIT is broadly accepted in academia and practice (e.g. Hu and Quan 2005; Kohli and Grover 2008; Kudyba and Diwan 2002; Lee and Menon 2000; Thatcher and Oliver 2001). Nevertheless, many IT projects still underperform their expectations and BVIT is still considered as understudied (Kohli and Grover 2008).

Research paper 1 takes up the research stream on BVIT and utilizes the value perception of practical decision-makers to explain how patterns in human decision processing may lead to deviations between the perceived BVIT and the actually realized performance effects. Methodologically, this paper builds a conceptual model on the basis of famous prospect theory (PT) from Kahneman and Tversky (1979) to investigate how such biased perceptions

of the BVIT can result in wrong decisions. For validating the explanatory power of the model, research paper 1 reports on its applications in the contexts of the productivity paradox and perception paradox. In these applications the model provides new insights about the origins of the paradoxes and derives retaliatory actions. That is, research paper 1 addresses the research objectives of providing additional explanations for the productivity paradox and the perception paradox as well as deriving retaliatory actions.

I.2.2 Chapter III: Normative Guidance on IS Decisions – How to Evaluate Investments in Big Data Analytics

Research Paper 2:

The Integration of the Fifth Dimension –

A Quantitative Framework on the Business Value of Big Data Analytics”

Two key issues that often force decision-makers to fall back on heuristics in IS decisions are the complex decision environment and the high amount of available information (Goes, 2013). The high pace of digital innovation continuously changes the state of the decision problem (Henfridsson and Bygstad 2013; Tilson et al. 2010; Yoo 2010). Decision-makers need to continuously re-evaluate former decisions and deal with new technologies where economic impacts can often only be guessed. Big data analytics (BDA) is a striking example where the described complexity complicates good IS decision making. In the term big data analytics, big data represents high data volume from a variety of data sources in different formats (Bendler et al. 2014), while analytics covers the extraction of knowledge from these big data (Müller et al. 2016). Although academia and practices agree that big data analytics will have a disruptive impact on business models (Chen et al. 2016; Chen et al. 2015), reality shows that organizations often struggle with BDA’s basics (Chen et al. 2015; Marx 2013). This is because technology investments in mass data storage and high speed computing do not create business value per se, but require a long-term, organizational evolution (Brynjolfsson and McAfee 2014; Chen et al. 2014). Moreover, often cited advantages of big data analytics are intangible like e.g. a better basis for decisions or a more profound knowledge on customers. Thus, there is a deep practical need for concrete guidance about how to determine the business value of BV to make good decisions. Practitioners demand assistance in how technological characteristics of volume, velocity, variety and veracity transform into economic effects. Research paper 2 addresses this need and constructs a modular model of the business value of BDA. Building on the economic consideration of information use as proposed by Stratonovich (1965), the model adjusts the

classic value of imperfect information for particularities of the new technology. Thereby, paper 2 has the research objective of providing a practical evaluation framework on the business value of big data analytics considering the technological characteristics of volume, variety, velocity, and veracity. Embedded in the research context, research paper 2 demonstrates the usefulness of normative decision theory for overcoming the problems of complexity inherent to IS decision making.

I.2.3 Chapter IV: Normative Guidance on Strategic Redesign Decisions

Research Paper 3:

Customer Experience Versus Process Efficiency:

Towards an Analytical Framework About Ambidextrous BPM

Comparable to the perception paradox which covers the observation that decision-makers perceive efficiency effects of IS as more valuable than the ability to establish competitive advantages, BPM scholars and practitioners also exhibit a one-sided perspective when setting strategic redesign objectives. Most redesign approaches operate on improving process performance as central objective whereas customer satisfaction is either completely neglected or only addressed indirectly. Rosemann (2014) criticizes this underrepresentation of explorative or customer-centric design approaches in BPM and points out that opportunities from innovative, IT-enabled processes are often outside the academic focus. He further states that digitalization makes explorative strategies ever more important and that process redesign requires a strategic rethinking towards the coexistence of customer-centric and efficient process designs (Rosemann 2014). From a capability perspective, Rosemann (2014) calls this coexistence “ambidextrous BPM” which means that organizations need to develop exploitative as well as explorative abilities at the same time. Thereby, exploitation refers to efficient fulfillments of basic customer needs, whereas exploration aims at “process designs that truly excite customers” (Kohlborn et al. 2014, p. 636).

Even increasing complexity, setting strategic design objectives additionally demands organizations to decide between risk-averse designs on the motto “better safe than sorry” and risk-taking designs in the sense of “nothing ventured is nothing gained” (Alexandrov 2015, p. 3001). With respect to this risk trade-off of process redesign, BPM academia and practice again overemphasize a single direction. Most popular approaches like six-sigma (Conger 2010) or value-based BPM (Bolsinger et al. 2011) strictly demand for risk-averse designs and neglect the opportunities of risk-taking designs. However, Alexandrov (2015)

shows that organizations which balance their strategies with risk-taking and risk-averse components are more successful than one-sided competitors. Thus, again a strategic rethinking in direction coexistence is required.

Taking together, decision-makers need to maneuver in the tension field of four archetype design objectives: 1) risk-taking and efficient, 2) risk-taking and customer-centric, 3) risk-averse and efficient and 4) risk-averse and customer-centric. Thereby, process and customer characteristics need to be taken into consideration. This is where research paper 3 aims to support decision-makers. The paper combines results from customer relationship management and BPM into an integrated model, which then assists decision-makers in determining correct strategic redesign objectives. Thus, this research paper addresses the research objective of providing a structured approach for choosing the right redesign objectives under explicit consideration of customer needs. Accordingly, the research paper addresses the intersection between the process layer and the layer of customers or business model.

Research Paper 4:

Design it like Darwin - A Value-based Application of Evolutionary Algorithms for Proper and Unambiguous Business Process Redesign”

Once the strategic objectives are set, decision-makers need to generate redesign ideas to reach these objectives. This second activity in the process of redesign is considered as most difficult. In practice, it is still more art than science (Kettinger et al. 1997; Limam Mansar and Reijers 2007). Limam Mansar and Reijers (2007) summarize the problem of generating new redesign ideas in a central question: “How to invent a new process design that is in one or more ways superior to the existing plan?” (Limam Mansar and Reijers 2007, p. 195).

As response to the deep practical need for rational guidance, the BPM community has developed various tools to enable the identification and generation of promising design ideas. However, most approaches still devote too high degrees of responsibility to decision-makers and there are still few normative theories that leverage computational abilities for this complex task (Bernstein et al. 2003). Academia mainly produced qualitative techniques that bear the risks of biased decisions or neglecting promising designs (Kettinger et al. 1997). Although more advanced techniques also emerged, applications of computational intelligence are still considered a relevant research gap (Vanwersch et al. 2015). Among the first approaches that utilize computational intelligence for the generation of redesign ideas (e.g. Min et al. 1996, Nissen 1998), especially applications of evolutionary algorithms (EA)

appear promising (Vergidis et al. 2012). The basic idea is to incrementally improve current designs in many simulative cycles until the gradual improvements form new, superior designs. However, the few existing applications can only operate on a limited number of process elements, more particularly, they cannot deal with data or event-based gateways or represent decision points. Moreover, they typically come up with ambiguous sets of designs and do not give a clear prioritization of ideas. Research paper 4 addresses these shortcomings and develops an application of computational intelligence to support practical decision-makers in a cost-efficient and systematic way to make the whole redesign process more robust against subjective vagueness. Thus research paper 4 covers the research objective of providing a computational tool for creating process redesign ideas

I.2.4 Chapter V: Normative Guidance on Operational Redesign Decisions

Research Paper 5:

An Economic Decision Model for Determining the Appropriate Level of Business Process Standardization

Having completed the strategic decisions on redesign objectives and being committed to a new design, decision-makers face operational decisions of implementation. Research papers 5 and 6 provide guidance on such implementation decisions for two central redesign approaches: business process standardization (BPS) and flexibilization. As for standardization, the key operational decision is about the scope of a (new) process design. In general, BPS means the alignment of process variants against a so-called master process (Münstermann et al. 2010; Reichert et al. 2015; Tregear 2015). The master process is typically an existing process variant or - in the context of this doctoral thesis - a newly designed target process. A process variant is an adjustment in the master process tailored to the peculiarities of the process context, i.e., the environment in which the variant is executed (Ghattas et al. 2014; Reichert et al. 2015). The inherent scope decision is about whether process contexts ought to be served by the master process or by the corresponding variants. The more contexts are assigned to the master process, the higher the level of BPS. Transferred to the implementation of new process designs, BPS covers the decision which process contexts should follow the new blue-print.

This operational scope decision requires the solution of the so-called BPS trade-off. (Manrodt and Vitasek 2004). Thereby, the BPS trade-off is the interplay of two conflicting effects: Whereas BPS boosts different internal dimensions of process performance, such as time, cost, and quality (Münstermann et al. 2010), it causes investments and may reduce an

organization's ability to meet customer needs (De Vries et al. 2006; Hammer and Stanton 1999). Although, there is a mature body of descriptive knowledge on how BPS affects different dimensions of process performance and on the partially conflicting nature of these BPS effects (Münstermann et al. 2010), only very few studies transform this descriptive knowledge into normative decision support for determining the appropriate BPS level (Münstermann and Weitzel 2008; Romero et al. 2015). Hence, research paper 5 addresses the research objective of providing such normative decision support on business process standardization.

Research Paper 6:

The Business Value of Process Flexibility - An Optimization Model and its Application in the Service Sector

Similar to BPS, also process flexibility refers to the coexistence of processes or process designs. Whereas BPS covers the decision about the assignment of process designs to process contexts, process flexibility refers to the orchestration of multiple processes or designs. Although, process flexibility is an immature and vague concept (Sethi and Sethi 1990), Goyal and Netessine (2011) postulate a practicable definition. Accordingly, process flexibility refers to the ability to create multiple outputs on the same capacity and to reallocate capacity between processes in response to realized demand (Goyal and Netessine 2011). This interpretation fits to organizations which provide multiple products in their business model aim to coordinate the underlying business processes in a way to react flexible on change in the demand distributions. The idea is to enable IT and employees to execute different process designs according to current market environment.

The general decision problem inherent to the desirable capability of flexible process execution, is the degree of flexibility. Although, a higher degree of flexibility enables organizations to shift more capacities to optimally exploit realized demand, the provision of such flexible capacity requires high cash outflows. Thus, decisions on flexibility always mean weighting up these higher cash outflows for establishment against the cash inflow potential of reactivity. Current research is mostly restricted to the manufacturing area or focuses on processes from specific application domains. Characteristics of the involved processes and outputs beyond capacity and demand that influence the appropriate level of process flexibility are barely considered. Moreover, most existing optimization models do not explicitly consider the positive economic effects of process flexibility or are restricted on how process flexibility reduces costs. Therefore, a thorough economic analysis of process

flexibility and a general decision support is missing. Accordingly, research paper 6 addresses the research objective of providing decision support on business process flexibility.

I.2.5 Chapter VI: Results, Limitations and Future Research

After this introduction, which aims at outlining the objectives and the structure of the doctoral thesis as well as at motivating the research context, the research papers are presented in Chapters II to V. Subsequently, Chapter VI presents the key findings, points out limitations and highlights areas for future research on descriptive and normative IS decision-making.

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II Descriptive IS Decision Theory – Investigating Paradoxes Inherent to the Business Value of IT

II.1 Research Paper 1: “The Business Value of IT in Light of Prospect Theory- A New Explanation for IT Paradoxes”

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Abstract:

A key problem with IT decision-making is that the real value contributions of IT projects are unknown ex-ante to their executions. Thus, an organization has to rely on the expectations and perceptions of its decision-makers. Moreover, these perceptions are prone to biases and display only a transfigured or irrational image of reality. This paper examines how these biases are related to the business value of IT (BVIT) and how IT decision-making can be rationalized. To this aim, a model is set up based on prospect theory, which is a frequently cited theory from behavioral economics used to descriptively analyze human value perception under risk. Applying the results found via prospect theory to IT decisions, the “perceived” BVIT is quantified and analyzed. Based on the model, the paper shows that the irrationalities rooted in human value perception provide explanations for two central paradoxes of IT. First, it reveals that they cause a disparity between the anticipated value-adding effects of IT and the actual measured outcomes, reflecting a famous observation within BVIT research known as the “productivity paradox of IT.” Second, recent studies show that IT increases the operational efficiency and competitiveness of organizations. However, only the operational effects are perceived in practice. In the paper, this one-sided perception is referred to as the “perception paradox of IT”. It is ultimately concluded that a rethinking of the position of IT within modern organizations and the establishment of suitable corporate governance mechanisms can resolve these issues, avoid irrationalities, and positively influence the performance impacts of IT.

II.1.1 Introduction

The globalization of today's economy has increased the competitive pressure on organizations. Companies must be able to react rapidly to changing customer needs or to technological innovations. Correspondingly, the role of IT "as a powerful competitive weapon" for encountering these challenges is becoming increasingly important, and every IT investment has to be critically evaluated with respect to the business value created (Mata et al. 1995, p. 487). This business value of IT (BVIT) is defined "as the organizational performance impacts of IT at both the intermediate process level and the organization wide level, and comprising both efficiency impacts and competitive impacts" (Melville et al. 2004, p. 287). A key problem for IT decision-making is that the value contributions of IT projects are unknown in the decision process; thus, the decision-makers' perceptions of the projects are determinate. A characterization of the abstract term "perception" in cognitive psychology is the sensory experience of the environment, which involves the recognition and the interpretation of external information (Cherry 2013). Thus, we define the *perceived BVIT* as the decision-makers' mental interpretation of IT performance impacts. A key problem with human value perception is that it is based on heuristics and prone to biases (Gilovic et al. 2002). Such mental shortcuts within human valuation processing lead to deviations between the IT value perceived by decision-makers and the objective IT value, and, ultimately, to irrational IT decisions.

The analysis of the perceived BVIT enables us to determine where these heuristics originate and how IT decision-making can be made rational. For example, we can derive solutions for the productivity and the perception paradoxes of IT. The productivity paradox refers to the observation that most IT investments fall short of their expected performance effects (Brynjolfsson 1993). In other words, decision-makers misperceive the BVIT. The perception paradox refers to the perceived value sources of IT. In general, the performance effects of IT can be divided into two categories: productivity and competitive effects (Melville et al. 2004). Productivity relates to internal value and is manifested in the reduction of operational costs (Drucker 1966). Competitive effects are associated with external value and typically show in competitive advantages (Barney 1991). In practice, however, it is mainly the internal value of IT that is perceived. In a global CFO technology study by Gartner (2013), only 10% of the respondents considered IT as a potential source of differentiation, whereas 31% perceived the value of IT in the enhancing of operations. Many researchers have promoted the role of IT as a source of competitive advantage and the need for investment in that type of IT (Devaraj and Kohli 2003; Santhanam and Hartono 2003). However, despite the

considerable successes of such investments in the past, this facet of IT value has only partly influenced the minds of practical decision-makers. We refer to this one-sided perception as the “perception paradox” of IT.

In this paper, we utilize the value perception of practical decision-makers as an innovative, analytical lens with which to examine the BVIT. In order to investigate the effects of the described irrationalities of IT decisions, we develop an analytical model for the human perception of IT value based on the famous prospect theory (PT) from Kahneman and Tversky (1979). They formulate a quantification of human value perception that incorporates several common patterns (e.g., loss aversion or asymmetric risk attitudes) frequently demonstrated in behavioral experiments. The application of their framework has already been beneficial for other economic research streams, especially capital market theory (De Giorgi and Hens 2006). Therefore, it may also be useful in deriving new insights for BVIT research. Although PT was originally designed for individual decision-making, it is at least partially applicable for corporate decision-making, as is the case for IT decisions. The perceived value function from PT remains valid for organizational value perception if the context of the organization is considered (Shimizu 2007) and if it is parameterized differently (Wen 2010). Investigating the BVIT through the “irrational” eyes of PT introduces a new research perspective that can complement, confirm, and enhance existing research results. The contribution of this paper is to provide a descriptive, analytical model of the perceived BVIT through which we can shed light on resolutions of the paradoxes of the BVIT.

The remainder of this article is structured as follows: In the next section, we describe the fundamental theoretical concepts that our perception model is based on to substantiate the existing research gap. Then, we analyze the foundations of the described paradoxes of IT, and apply the derived results to obtain additional explanations for their existence. Finally, we discuss our results and provide an outlook on future research.

II.1.2 Theoretical Background

II.1.2.1 The Business Value of IT

In the 1960s and 1970s, information technology (IT) was perceived as the “biggest technological revolution men have known” (Snow 1966, p. 650). However, the technology could not meet these high expectations. As a result, a great disillusionment with IT arose in the 1980s. During this time, economic productivity stagnated, while the number of computers increased more than threefold (Brynjolfsson 1993). Moreover, the first scientific

studies about the realized value of IT provided controversial results and thus exacerbated doubts about technology (Yorukoglu 1998). Even Nobel Laureate Robert Solow addressed the productivity shortfall of IT investments, which became known as the “productivity paradox,” in his famous quote: “We see computers everywhere except in the productivity statistics” (cited after Brynjolfsson 1993, p. 67). The value discussion finally reached its climax in 2003, with Nicholas Carr’s aggressive article “IT Doesn’t Matter” (Carr 2003). In this article, Carr argues that IT shows the basic characteristics of infrastructure technologies and, therefore, cannot be a source of competitive advantage. The productivity paradox and the heated debate about the BVIT endangered the position of the information systems research community. Consequently, scholars established the BVIT research stream to focus on the “how’s” and “why’s” of IT value creation within a firm or a network of firms (Kohli and Grover 2008). The scientific objective is basically “to fully capture and properly attribute the value generated by IT investments” (Kohli and Grover 2008, p. 27). Indeed, the scientific efforts of the research stream have been successful. Today, the existence of the BVIT is increasingly becoming accepted (Kohli and Grover 2008; Hu and Quan 2005; Kudyba and Diwan 2002; Thatcher and Oliver 2001; Lee and Menon 2000). Nevertheless, the value proposition of IT is challenged again and again, as evident in articles such as “The CIO Dilemma,” published by the trading magazine *InformationWeek*, in which the diminishing role of CIOs is described and the failure of IT to deliver innovations is condemned (Martin 2007). Scientific discourses and recurring debates have kept the research discipline up-to-date and fascinating for the last 30 years, and its research questions are still considered understudied (Kohli and Grover 2008).

Before differentiating the objective from the perceived value of IT, we start with defining the abstract terms *IT* and *BVIT*. Within BVIT research, IT is often mentioned together with information (and communication) systems (IS), and often these terms are not clearly distinguished. Therefore, this paper employs a comprehensive understanding of IT, utilizing the abbreviation to reference various technology classes, such as enterprise architectures, databases, software applications, servers, networks, and other infrastructure components. Combining the economic concept of value and the comprehensive understanding of IT leads to the concept of the BVIT, which is defined as “the organizational performance impacts of IT at both the intermediate process level and the organization-wide level, and comprising both efficiency impacts and competitive impacts” (Melville et al. 2004, p. 287). A special attribute of these effects is that they can be realized in multiple strategic dimensions. Similar to Weill and Vitale (1999), Oh and Pinsonneault (2007) describe a framework where the

value of IT is classified into three strategic effect types. IT investments can aim at minimizing “operational costs while maintaining a satisfactory level of quality,” “providing a unique combination of product attributes at a reasonable cost,” or increasing the sales volume of organizations (Oh and Pinsonneault 2007, p. 245). In other words, IT investments are intended to increase the revenues or reduce the costs of an organization. Investments that increase the sales volume and provide a higher degree of product differentiation affect the firm’s revenues, defined as the product of the sales volume and sales price. Increased sales volume contributes directly to revenues, and increased product differentiation can typically be transferred into higher sales prices (Nault and Dexter 1995). We refer to IT investments that are characterized by revenue effects as revenue investments. IT investments that are aimed at reducing operational costs are defined as cost investments. The above reasoning demonstrates that IT investments typically underlie an ambiguity concerning their strategic and monetary effects so far.

The perceived BVIT is the decision-maker’s mental interpretation of IT performance effects, and represents the expectations for the technology ex-ante to the investment. Thus, it serves as a kind of filter for IT investment opportunities. Only those IT projects that are perceived as highly valuable will be put into practice. Consider a decision about the implementation of a new ERP system, where different software suppliers offer their product and a firm has to choose its favorite. The firm will choose the software with the highest perceived business value. Only the chosen ERP system can create real performance effects for the firm, and the other decision alternatives never create any BVIT. In other words, the perceived value constitutes the first obstacle for IT to create any business value and determines which IT projects are implemented and which are rejected. The implemented projects in turn influence the realized performance effects (i.e., the BVIT). Therefore, the perceived and the objective BVIT both refer to the same underlying construct, which is the performance effects of IT, in the given example to the performance of an ERP system. However, the irrationalities inherent in the perception process can make the implemented IT or the chosen ERP system deviate from the rational optimum. As a result, the BVIT may fall short of its potential. The identification and avoidance of irrationalities can, therefore, improve the BVIT.

The example of the ERP system illustrates the close connection between perception and reality with regard to the BVIT. However, there are important structural differences between these concepts. First, the BVIT refers to the realized economic outcome of IT investments, which includes cost reduction and revenue improvement. The perceived BVIT is about how decision-makers perceive the benefits they can gain from IT investments, not about the

actually realized benefits. In other words, the BVIT is a real and objective metric, whereas the perceived BVIT is a mental and subjective construct. Second, both approaches become relevant at different time points relative to the investment decision. The BVIT becomes relevant in the value chain of the organization ex-post to the decision and focuses on past developments. The perceived value is pertinent to the decision process (i.e., ex-ante to the decision), and is orientated toward the future. Third, due to its ex-post character, the BVIT is measurable and, thereby, certain. In contrast, the perceived BVIT is about future performance effects that underlie uncertainties and risks. Fourth, unlike the objective BVIT, the perceived BVIT is prone to biases and heuristics. These factors ultimately lead to deviations between the BVIT and the perceived BVIT.

Analyzing the performance effects of IT from a perceptual perspective is promising for the corresponding research stream. Performance effects are not understood as a realistic outcome but as the outcome of an economic decision within an organization. Ultimately, it is organization-specific factors, not advance perceptions that determine how IT affects the performance of an organization. However, the particular manifestations and characteristics of the performance effects are also a consequence of an organizational decision. Therefore, it is relevant to consider not only the characteristics of IT in its role within the value chain of an organization but also its attributes within the decision process. Although the perceptual approach cannot be seen as substitutive or superior, it may contribute to a more holistic understanding of the BVIT. This research expands the spectrum of distinguishing features of IT investments.

II.1.2.2 Prospect Theory and the Quantification of Perceived Value

In order to quantify the perceived value of IT, we apply PT, which is probably the most prominent descriptive model for human value perception. In the existing IS literature, PT has been applied to explain phenomena such as the escalation of software projects (see, e.g., Keil et al. 2000), the bidding behavior of consumers in online auctions (Wu et al. 2009), and the deviations of expectations regarding technological innovations between developers and users (McAfee 2009). However, no analytical model exists that introduces PT and the related behavioral aspects to BVIT research (Fleischmann et al. 2014). The analytical approach is crucial for the derivation of reliable results from PT (Bromiley 2009). In general, PT analyzes human decision-making with respect to observable violations of expected utility theory (EUT) as a benchmark for a rational value understanding. It represents an alternative approach that complies with the observed violations. Whereas PT descriptively analyzes how

human beings make decisions under risk, EUT normatively investigates how decisions under risk should be made optimally and rationally. With decisions under risk, the possible outcomes and the corresponding probabilities of occurrences for those outcomes are known. In other words, a formal representation of the decision problem is possible. In contrast, decisions under uncertainty are characterized by unknown probabilities of occurrence (Tversky and Kahneman 1981).

PT identifies four characteristics of human value perception that are not addressed in EUT. First, decision-makers evaluate alternatives with respect to “gains” and “losses” relative to a given reference point. In this context, the terms *gain* and *loss* do not refer to their economic interpretation as positive or negative profits; rather, they are defined as positive or negative deviations from the reference point. Second, decision-makers are characterized by loss aversion, which means that their dislike for losses is by a factor of about 2.25 higher than their fondness for gains (Kahneman and Tversky 1979). Third, decision-makers have asymmetric risk attitudes, which means that they are risk-seeking toward losses and risk-averse toward gains. Fourth, the value perception is not exclusively determined by the perception of the outcomes; it is also influenced by the perception of the corresponding probabilities of occurrences for these outcomes. Human beings nonlinearly transform the probability scale by overweighting small probabilities and underweighting moderate and high probabilities in their perceptions (Tversky and Kahneman 1992). Kahneman and Tversky (1979) integrate the first three effects concerning the perception of a single outcome O_i in the so-called value function $V(O_i)$, where \bar{O} represents the reference point, α the risk attitude, and β the loss aversion.

$$V(O_i) = \begin{cases} (O_i - \bar{O})^\alpha & \text{for } O_i \geq \bar{O} \\ -\beta(\bar{O} - O_i)^\alpha & \text{for } O_i < \bar{O} \end{cases} \quad (1)$$

The value function per se does not reflect the described risk attitudes and loss aversion, but a specific parametrization of the function is required. To implement loss aversion, β has to be strictly greater than one, and to implement the described risk attitude α has to lie within the range between one and zero. **Fig. 1** schematically illustrates the value function for such a parameterization. The difference in the valuation of losses and gains becomes obvious at the origin of the function, which is the reference point. Negative (losses) and positive (gains) deviations from that reference point are evaluated using different mathematical functions. The function for the loss part is steeper than that for the gain part. The different slopes reflect the concept of loss aversion. Additionally, the curvatures of the functions are different. The

convexity of the left-hand side indicates the risk-seeking loss valuation, whereas the concavity of right-hand side implies the risk-averse gain valuation.

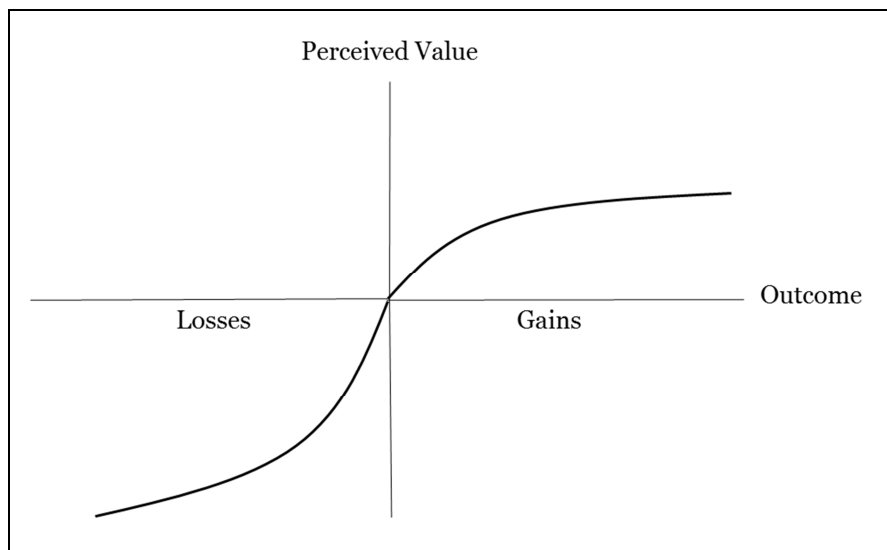


Fig. 1 Value Function from PT

Viewed in isolation, the value function already reveals key observations about human value perception. However, it is insufficient in completely describing this complex process. Decision behaviors, such as insurance contracts as an example of risk-averse loss perception and gambling as an example of risk-seeking gain valuation, contradict the value functions. To overcome this shortcoming and to provide a closed model for human value perception, Kahneman and Tversky's (1979) theory, along with other descriptive theories for human decision-making, expands the idea of value perception from a narrow outcome-oriented perception to a combined perception of outcomes and probabilities. Through their concept of diminishing sensitivity, Tversky and Kahneman (1992) established the psychological foundation for the integration of probability perception. This concept states that human beings become less sensitive to changes in probabilities as they move away from their natural reference points of certainty (probability equal to 100%) and impossibility (probability equal to 0%). In other words, small probabilities are overvalued, while high and moderate probabilities are undervalued. The so-called weighting function from PT transfers objective probabilities p_i to perceived probabilities $w(p_i)$ by rescaling the objective probabilities consistent with the concept of diminishing sensitivity (Tversky and Kahneman 1992). The rescaling is achieved analytically via an inverse S-shaped weighting function that is first concave and then convex. Several empirical studies have validated this functional form (see, e.g., Gonzalez and Wu 1999).

$$w(p_i) = \frac{p_i^\gamma}{(p_i^\gamma + (1-p)^\gamma)^{\frac{1}{\gamma}}} \quad (2)$$

Finally, PT combines the value function and the weighting function into a combined function for the perceived value PV , which is strongly aligned with EUT. This is especially appealing because PT can then be interpreted as “a special case of the widely accepted normative theory” (Gonzalez and Wu 1999, p. 158). The product of the weighted probability $w(p_i)$ and the outcome $v(O_i)$ equals the perceived value for that outcome. The sum of the perceived values for all possible outcomes represent the perceived value of the decision alternative. Thus, the perceived value of an alternative $PV(\tilde{O})$ resembles the functional form of an expected value:

$$PV(\tilde{O}) = \sum_{i=1}^n w(p_i)v(O_i) \quad (3)$$

The adjustment of the value function by the weighting function has important implications for the results on human value perception. The participation of people in lotteries is not compatible with a risk-averse gain valuation, as indicated in the value function. Following the definition of risk aversion, a risk-averse individual would never pay a participation fee that exceeds the expected value of the lottery winnings. However, if the small probability of winning a lottery is overvalued, the perceived value of playing the lottery can also exceed its expected value. Therefore, the overvaluation of small probabilities can override the undervaluation of the risky decision from the pure outcome perception and transform the risk-averse gain perception into a risk-seeking one. An equivalent example on the loss side is the conclusion of insurance contracts against large losses that occur with small probability. In this case, the risk-seeking loss perception that contradicts such a behavior is changed into a risk-averse perception by the overweighting of small probabilities. Combining both functions introduces the fourfold risk pattern (Tversky and Kahneman 1992). Losses underlie a risk-seeking perception for large and moderate probabilities and a risk-averse perception for small probabilities. Equivalently, the perception of gains is risk-averse for large and moderate probabilities and risk-seeking for small probabilities (Tversky and Kahneman 1992).

II.1.3 The Perceived Business Value of IT

In order to transfer the notion of individual value perception to the perceived value of IT within an organization, it is important to address three main issues. First, the perceived value of an outcome is not identical to the perceived value of an investment, as the value of an investment requires the consideration of the status quo and the time value of money. Second, the concept of perceived value has to be matched to the strategic dimensions of the objective BVIT to achieve a closed model that considers the unique aspects of IT investments. Third, the applicability of PT is generally restricted to individual decision-making rather than firm-level (group) decision-making. When managers make IT investment decisions, they may go through several rounds of meetings, discussions, and assessment. It is unclear whether PT is applicable to this kind of relatively rational group decision-making process.

Although PT focuses on one-period outcomes rather than on investment, the functional form of the perceived value is not restricted to one-period outcomes. In order to transfer the perceived value function from equation (3) to the context of IT investments \tilde{I} , we introduce different payment dates and the time value of money. Therefore, we replace an outcome O_i with an outcome for the net present value of the IT investment I_i . The net present value is defined as the difference between the discounted sum of the positive payments associated with the investment and the initial investment outflows. Ultimately, to derive the perceived value of an IT investment $PV(\tilde{I})$, we additionally need to consider the perceived value of the affected payments in the status quo $PV(SQ)$.

$$PV(\tilde{I}) = \sum_{i=1}^n w(p_i)v(I_i) - PV(SQ) \quad (4)$$

To account for the two different value forms originating from IT investments, we match the dichotomy from the strategic dimensions of the objective value and the perceived value functions from PT. Therefore, we must determine whether IT investments are “framed” as a potential reduction of organizational losses or as a potential increase of organizational gains in the respective strategic dimensions. The concept of framing also originates from PT and states that variations in the formulation of a choice problem (i.e., in terms of gains or losses) provoke different value perceptions (Tversky and Kahneman 1981). If a problem is formulated in the gain context, it is accordingly evaluated from a risk-averse point of view for large and moderate probabilities and from a risk-seeking point of view for small probabilities. The risk attitudes, however, are reversed if the same problem is formulated in a

loss context. The BVIT can originate from revenue investments and cost investments; typically, revenues are perceived positively, and costs are perceived negatively. Consequently, the hypothesis arises that revenue investments are framed in a gain context and cost investments in a loss context. This hypothesis has been confirmed by Fogelström et al. (2009) within the IT context of market-driven software product development. In a survey with 71 student participants from a software engineering master's program, they empirically demonstrate that software requirements associated with the revenue dimension underlie a risk-averse value perception, whereas software requirements associated with the cost dimension trigger a risk-seeking value perception. For our model, this means that the perception of revenues R can be described by the gain value function and that the perception of costs C follows the loss value function. In other words, the reference point for IT investments is zero. Therefore, the perceived values for cost and revenue investments can be described in the following form:

$$\begin{aligned}
 PV(\tilde{R}) &= \sum_{i=1}^n w(p_i)(R_i)^\alpha - (SQ_R)^\alpha && \text{revenue investments} \\
 PV(\tilde{C}) &= \sum_{i=1}^n w(p_i) (-\beta(-C_i)^\alpha) + \beta(-SQ_C)^\alpha && \text{cost investments}
 \end{aligned} \tag{5}$$

Finally, to transfer the concept of perceived value to the BVIT, we must consider that IT decisions are typically not individual; they are organizational. Indeed, the current literature shows no consensus about the question of whether PT can be applied for organizational decision-making. On the one hand, there is empirical evidence that PT can explain the risk–return decisions of organizations (e.g., Bromiley 1991; Fiegenbaum and Thomas 1988; Singh 1986). On the other hand, organizations also show behaviors that do not comply with original PT, such as the conservative behavior of organizations in the presence of poor performance (e.g., Chattopadhyay et al. 2001; Cameron et al. 1987). As is often the case, modern research results unite these opposing findings. The value function from PT can be applied to organizational valuation if the context of the organization is considered (Shimizu 2007) and if it is parameterized differently (Wen 2010). Whereas Kahneman and Tversky (1979) operationalize their value function with $\alpha = 0.88$ and $\beta = 2.25$, Wen (2010) derives a parameterization with $\alpha = 0.45$ and $\beta = 1.69$ for organizations. Thus, organizations underlie the same perception effects of asymmetric risk attitudes and loss aversion but on a more moderate level as compared to individuals. The applicability of the weighting function has, to the best of our knowledge, not yet been tested in an organizational context. However, the results from Wen (2010), which indicate an ambiguous rather than fourfold gain–loss

perception, suggest that organizations do not follow the fourfold risk pattern and that they scale probabilities nearly correctly. Wen (2010) finds clear evidence for a risk-averse gain perception and a risk-seeking loss valuation. If organizations were subject to a fourfold risk pattern, it is likely that the clear results for the risk attitudes could not have been derived. Because there are indications that organizations scale probabilities correctly and there are no contradictory research results, we assume that organizations do not follow the fourfold risk pattern and that the weighting function is not descriptive for organizations. Consequently, the functions for perceived IT values are transformed to the following equations:

$$\begin{aligned}
 PV(\tilde{R}) &= \sum_{i=1}^n p_i (R_i)^\alpha - (SQ_R)^\alpha && \text{revenue investments} \\
 PV(\tilde{C}) &= \sum_{i=1}^n p_i (-\beta(-C_i)^\alpha) + \beta(-SQ_C)^\alpha && \text{cost investments}
 \end{aligned} \tag{6}$$

With the preceding argumentation, we introduced our model of the perceived value of IT, an approach that is new to this research stream and, thus, represents a new analytical lens for observing phenomena within this context. We illustrated that the different dimensions of strategic IT value can be assigned to different sections of the perceived value function from PT. This perceived value function incorporates four important features of human valuation perception: asymmetric risk aversion, loss aversion, reference point valuation, and nonlinear probability transformation. Although developed for individual value perception, the theory can be transferred to organizational value perception, with the exception of probability scaling, by an adjustment of the parameterization. We conclude that organizations evaluate IT revenue investments as organizational gains and, thereby, differently than they evaluate IT cost investments. Whereas cost investments are perceived to reduce organizational losses and are accordingly evaluated from a risk-seeking perspective, revenue investments are considered to increase organizational gains and are evaluated from a risk-averse perspective. Moreover, cost investments are typically perceived to be more valuable as a result of the loss aversion. In the following, we apply our model to a concrete IT investment decision to analyze the productivity and perception paradoxes of IT. Therefore, we need to model the effects and the risks of an investment option. As both the isolated success of the IT project and the business environment can influence the effects of the investment, we consider multiple possible outcomes. The effects of an investment are then represented by the expected changes in the costs or revenues relative to the status quo μ . The risks of an investment are modeled as the variance of the relative effects σ^2 .

In the appendix, we show that the perceived BVIT from formula (6) can be approximated by the application of a two-step Taylor series for any probability distribution. This approximation describes the BVIT according to the first two moments of the underlying probability distribution: the expected effects and their variance. Additionally, the approximation makes revenue investments and cost investments mutually comparable, as their expressions are brought down to a similar functional form.

$$\begin{aligned}
 PV(\tilde{R}) &\approx \alpha(SQ_R)^\alpha \left(\mu_R + \frac{1}{2}(\alpha - 1) \mu_R^2 + \frac{1}{2}(\alpha - 1) \sigma_R^2 \right) && \text{revenue investments} \\
 PV(\tilde{C}) &\approx \beta \alpha(-SQ_C)^\alpha \left(\mu_C - \frac{1}{2}(\alpha - 1) \mu_C^2 - \frac{1}{2}(\alpha - 1) \sigma_C^2 \right) && \text{cost investments}
 \end{aligned} \tag{7}$$

II.1.4 The Paradoxes of IT

II.1.4.1 The Perception Paradox of IT

BVIT research has shown that IT productivity is mainly associated with improvements in customer satisfaction, product and service quality, and convenience (i.e., effects are associated with revenue investments) (Papp 1999). Surprisingly, in practice this aspect of the BVIT is only partly perceived, and the cost-reduction effects of IT are more highly valued (Gartner 2013; Papp 1999; Henderson and Venkatraman 1993). This misperception is due to a variety of reasons. First, the revenue effects of IT are often intangible and, therefore, more difficult to quantify than the effects on costs are, demotivating managers from making revenue investments in IT (Papp 1999). Second, IT revenue investments typically face a higher risk than operational investments do because of the uncertainty of the competitive environment. IT can only create revenues via the interplay with market and environmental factors. Given the underlying dynamics of these factors, the risk of revenue investments is typically higher. Third, the information asymmetry between the users of IT and the senior managers of the organization supports such a biased cost focus. A disparity exists between the successes perceived by the two stakeholder groups ex-post to the investments. Whereas users experience the positive aspects of technology investments (e.g., service quality), senior managers do not realize these intangible effects; rather, they note only the high IT expenditures. As a result, senior managers become frustrated with IT, are not aware of the technology as a strategic asset, and view cost reduction as the main objective for IT decisions (Hirschheim and Lacity 2000).

All of these explanations take a perceptual perspective on IT decisions. Because the revenue effects of IT decision are intangible, decision-makers perceive them as more risky. The information asymmetry and the associated frustration at the top-management level

directly provoke such a one-sided perception. As PT is an acknowledged approach to quantify the value perceptions of human beings and organizations (Wen 2010), it may provide additional insights and explanations for this perceptual issue. The behavioral element's loss aversion and asymmetric risk attitudes may further confirm the existence of this paradox. PT formulates that loss reduction is more valuable than an equal amount of gain increase. If the risks of gain increases and loss reductions are also considered, the asymmetric risk attitudes reinforce the perceptual dominance of loss reductions. In other words, the risk diminishes the perceived value of gain increases, but amplifies the perceived value of loss reductions. Because cost investments are framed as loss reductions and revenue investments as gain increases, cost investments inherit the perceptual dominance of loss reductions.

Based on our model, we can prove this claim analytically. To that end, we compare the perceived values for two identical IT investments that differ only in their type. In doing so, we distinguish the perceptual effects described by PT from the other explanations, such as the different risk–return profiles. This controlled setting enables us to show that the perception paradox still holds if the other explanations are not given, and that the irrational value perception is responsible for the perception paradox. Even if this constructed decision between two identical investments is unrealistic, the proof under the artificial conditions suggests that the true explanation for the paradox does not lie exclusively in one of the presented approaches but in a combination of them. The application of PT, therefore, complements and enhances the existing theory in this regard.

The mathematical proof is depicted in the appendix. The proof implies that the perception paradox holds true for identical IT investments with positive expected effects. If the information provided about the investments suggests positive performance effects, loss aversion and asymmetric risk attitudes can explain a biased choice between cost and revenue investments. This condition is probably fulfilled in reality. In general, high-level executives make IT decisions based on proposals from the IT department; moreover, the IT department is unlikely to propose investment opportunities with negative business cases to the senior executives (Tallon et al. 2001). Ultimately, the analysis reveals that the perception paradox has a negative influence on the BVIT, as it implies that more valuable revenue investments with higher expected effects are eschewed in favor of objectively less valuable cost investments.

II.1.4.2 The Productivity Paradox of IT

The possible explanations for the productivity paradox can be classified into four categories. First, unique characteristics of IT capital investments, such as the high pace of technological improvements, require organizations to replace or upgrade their IT more frequently than they do other capital investments. With every adjustment of the IT landscape, an organization loses experience effects, and productivity decreases (Yorukoglu 1998; David 1991). Consequently, the overall productivity effects of IT investments are smaller than those for traditional investments. Second, measurement errors in pioneer studies on the value of IT may be responsible for the emergence of the productivity paradox. These measurement errors stem from the general weaknesses of productivity statistics, which become especially relevant within the context of IT productivity (Denison 1989). Productivity statistics typically underestimate quality and speed improvements, which are exactly the main benefits of IT investments (Brynjolfsson 1993). Third, the value of IT could be of a redistributive rather than a creative nature. In other words, IT may be valuable to certain organizations but unproductive when considering several competing organizations. This is because the value of IT can be grounded in the exclusivity of information, enabling an organization to attract market shares from competitors (Brynjolfsson 1993). Fourth, and probably most obviously, the productivity paradox exists because of poor investment decisions or failures in the management of IT projects. Indeed, empirical results illustrate that the success of an IT project depends highly on correct management and valuation procedures (Petter et al. 2013).

With the consideration of the measurement errors and the application of more sophisticated methods, a significant number of studies have shown the existence of the BVIT (e.g., Tallon et al. 2001; Gurbaxani et al. 1998). However, the valuation issue of IT is still valid today and is often referred to as the “new productivity paradox.” The new productivity paradox was coined by Anderson et al. (2003) and postulates that although IT returns do exist, the estimates for these returns tend to be overestimated (Dewan et al. 2007). One explanation for the new productivity paradox is hidden IT capital. Brynjolfsson and Hitt (1995) argue that IT investments are always carried out in a decentralized fashion, which makes it hard to estimate and track the complete extent of invested capital. Underestimating the invested capital leads automatically to an overestimation of IT returns. Another explanation for the new productivity paradox lies in complementary organizational investments that typically follow IT investments. Unlike traditional capital investments, IT investments require organizational changes to create the expected return. These additional investments in the organizational capital are often not considered in IT return estimates.

By analyzing the new productivity paradox within our model, we can provide an alternative, or complementary, explanation for the observation. Although the true explanation is likely to be a mixture of the presented notions, every additional part of the puzzle enables the entire theory to better explain reality. Having shown the preference for IT cost investments, we also focus the analysis of the new productivity paradox on this investment type. Readdressing the derived perceived value of cost investments, it becomes evident that the variance and, therefore, the risk of such investments are perceived positively. This is because of the risk-seeking valuation of organizational losses. The reasoning can be illustrated mathematically by showing that the first derivative of the perceived value function with respect to the variance is strictly positive (see appendix).

As a consequence of the positive valuation of risk ($\alpha < 1$), the BVIT is overestimated relative to the expected effects. In other words, the perceived value of IT is larger than the expected value of IT. If a failure is defined as a negative deviation from the target value, assigning a higher value to these investments naturally leads to a higher failure rate.

II.1.4.3 Resolutions for the Paradoxes

At the same time our model provides new insights into the origins of the paradoxes, it also derives two possible resolutions for them. First, a shift in the corporate culture concerning the reputation of IT within an organization can help to overcome the irrationalities in the decision process. We demonstrate that loss aversion and asymmetric risk attitudes are at least partly responsible for the perception and productivity paradoxes. A possible solution for the paradoxes can be a change within the mindset of practical decision-makers. If IT is no longer understood as a cost factor but as a source of competitive advantage and transformability, basic issues of the paradoxes can be resolved. Within our model, this shift in perspectives results in an adjustment of the reference point from a pure gain–loss perspective (reference point equals zero) to a status quo consideration. In terms of PT, the framing of the different investment types is eliminated. Consequently, a reduction of costs and an increase in revenues are both perceived as an increase in profits. As a result, cost and revenue investments are perceived equally, and at least one foundation of the perception paradox can no longer exist. Moreover, the productivity paradox is also solved with such a switch in perspectives; the overvaluation of IT cost investments is replaced by undervaluation. Similar to risk-dependent overvaluation, undervaluation becomes more extreme for riskier investments. A higher risk results in the realization of more extreme effects, both in the positive and negative directions. The loss aversion causes decision-makers to perceive the

more positive effects as less valuable relative to their negative perception of the more extreme downsides. From an economic point of view, undervaluation is probably less problematic than overvaluation, as the only investment opportunities executed are those still profitable after a risk discount. Consequently, rather than the false decision-making described in the productivity paradox, decision quality increases due to more prudent value perception. This argumentation only holds if an organization has sufficient investment opportunities. If this is not the case, the organization misses favorable investment opportunities and, thereby, again reduces the value of their IT. However, in a realistic setting, the IT budget is probably smaller than the firm's investment opportunities.

A second possible resolution for these incidents of perception biases and, therefore, for the paradoxes is the establishment of financial constraints and corporate governance mechanisms. Wen (2010) empirically demonstrates that the ambiguity and irrationalities in organizational decision-making can be prevented if such control strategies are executed, although the individual decision-makers still underlie these issues. The enhancement of corporate governance mechanisms, "high cash flow rights of controlling groups, high percentage of board seats held by non-controlling groups, high ownership of board members and independent director" are adequate actions to overcome the problems associated with irrational decision-making (Wen 2010, p. 126).

II.1.5 Discussion and Conclusion

BVIT research analyzes the performance effects of IT at the firm level. This research stream originates from historic doubts regarding the productivity impacts of IT investments. For the last 30 years, BVIT researchers have focused on alleviating these doubts and on analyzing the basic conditions and attributes of IT value. In addition to empirical and analytical approaches, the conceptual research stream applies economic theories to construct the scientific underpinning for the value proposition of IT. We take up this approach and develop the concept of the perceived BVIT. The perceived BVIT is defined as the decision-maker's mental interpretation of potential IT performance effects. Both concepts are different constructions of the same object and are, thus, related to each other. The perceived BVIT determines the IT investment opportunities chosen in the decision process and, ultimately, the structure of the IT landscape. In this way, it serves as a kind of filter for IT investments. Only IT investments with a high perceived BVIT are executed and create BVIT for organizations; opportunities with a BVIT perceived as low are not implemented and, thus, not associated with the BVIT. The key problem of IT value perception is that it is prone

to the biases of loss aversion, of reference point–dependent valuation, and of asymmetric risk attitudes. To quantify and investigate the effects of these biases on IT decision-making, we set up a model for BVIT perception by applying PT. Based on our model, we ultimately show that the classical biases, inherent in human value perception, lead to irrational perception schemata, such as the preference of cost investments over revenue investments (perception paradox) and the structural overvaluation of IT benefits (productivity paradox). The perception paradox biases the investment decision toward cost investments; objectively more valuable revenue investments may be neglected in favor of objectively less valuable cost investments. The misperceptions associated with the productivity paradox lead to a high proportion of IT investments that cannot meet expectations and, thus, to a riskier investment strategy. Overall, we can state that the biased perception makes the selection of IT investment irrational. Therefore, in reality, the realized BVIT is lower than it could be. **Fig. 2** illustrates our framework and our research results.

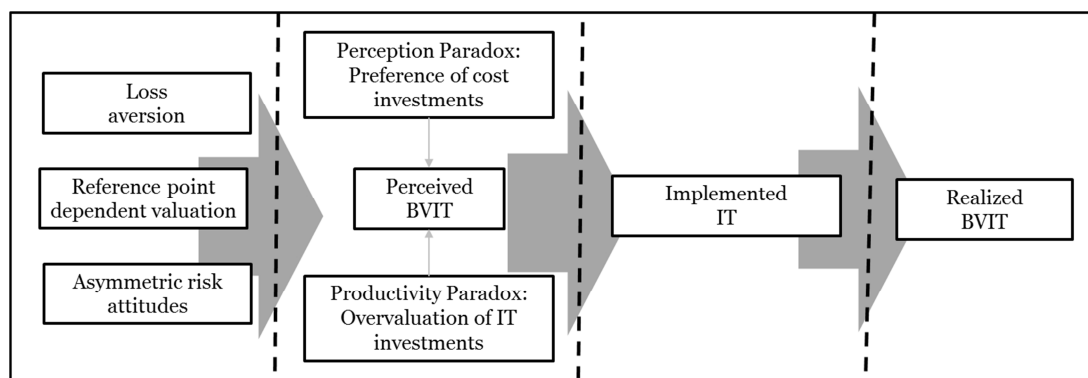


Fig. 2 The Perceived Value of IT

A better understanding of the irrationalities influencing IT decisions can provide the basis for the derivation of potential solutions and retaliatory actions. A possible approach is an adjustment of the corporate culture. If IT is perceived as a value driver, and not as a cost factor, of organizations, the value paradoxes are corrected automatically. The basic mechanisms of PT still hold, but the elimination of the framing effects resolve the ambiguous value perception. A second approach for the avoidance of an irrational selection of IT projects is the establishment of adequate corporate governance mechanisms and financial constraints. This is because both strategies avoid loss aversion and asymmetric risk attitudes in organizational decision-making and, therefore, resolve the ambiguous perception at its origin.

The scientific contribution of this paper is twofold. First, we apply one of the most honored economic theories to the context of BVIT research and quantify the perceived BVIT. In

doing so, we expand the toolkit for future analyses and studies in this discipline. Second, we theoretically prove that irrationalities in human valuation behavior are (at least partly) responsible for the existence of two fundamental paradoxes of IT. For this reason, we want to encourage a rethinking within the practical perception of IT. We analytically show that the value of IT would be higher and perceived more accurately if decision-makers avoid unfairly viewing IT departments as cost factor. This result is somewhat philosophical and can be criticized as suffering from a certain tautology. Indeed, the notion that IT creates value if this value is also perceived, can be described as a self-fulfilling prophecy. However, the loss aversion and asymmetric risk assessment observed in human behavior explicitly require this kind of rethinking.

Although PT has already been applied in IS research for the explanation of certain phenomena, such as the escalation of IT projects and the bidding behavior in software projects, it has not yet been established as a general theoretical approach for BVIT research (Fleischmann et al. 2014). The reason for this may be that the conceptual and quantitative research streams typically focus on the performance effects of the *existing* IT landscape in their organizational environment and, frequently, do not consider the existing IT as stemming from prior decision problems. Thereby, the *ex post* BVIT is their main research object. In contrast, the analytical research stream focuses foremost on the *ex-ante* BVIT and develops decision models that determine the optimal selection of IT projects. We adopt this point of view of an *ex ante decision problem*, but we descriptively analyze how the decision problem might be approached in practice. In doing so, we adopt the predominant perspective of the analytical research stream to focus on the main research objective of the empirical and conceptual approaches. As a result, this study investigates not only the characteristics of IT in its role in the value creation of an organization but also its attributes within the decision process. Features such as the risk–return profile, the type of IT investment, and the corporate governance and culture should be integrated in further analyses of the BVIT.

Thus, our approach complements the existing conceptual underpinning for BVIT research, as it introduces a new perspective on the issue. The same holds true for the explanation of both of the paradoxes. The application of PT reinforces the extant research results from another perspective and provides additional insights regarding the resolution of the paradoxes. Therefore, the theoretical contribution of our paper to BVIT research and the two paradoxes does not lie in a radical reorganization of the conceptual background, but in the expansion of it. With every complementary contribution, it is critical to question whether the presumably higher explanatory power of the theory justifies the higher degree of complexity. As is often

the case in economic research, the answer to this question is: it depends. More specifically, it depends on the validity of the research results. If the additional consideration of PT enhances the explanatory power of the entire theoretical framework of BVIT research, the higher complexity is justified. As PT focuses on different aspects than the existing theoretical concepts do, the explanatory power of the entire framework is likely to increase. However, the final answer to the validity question can only be found through quantitative and empirical analyses. Based on our findings, we can derive two central hypotheses for such an empirical validation. First, the higher the firm's degree of loss aversion and asymmetry of risk attitudes is, the larger is the portion of its IT investment portfolio focused on the reduction of operational costs. We have theoretically shown that more pronounced biases lead to a less balanced perception of cost and revenue investments and, consequently, to a less balanced IT landscape. Second, the higher the firm's degree of loss aversion and asymmetry of risk attitudes is, the higher is the perceived failure rate of the firm's IT investments. Our model suggests that more pronounced biases lead to a higher overestimation of IT benefits, which, in turn, more easily provokes frustration with the investments. The appropriate methodology for the validation of these hypotheses is probably an empirical field study. The loss aversion and the asymmetry of risk attitudes of the firm's decision-makers can be applied as independent variables. Additionally, variables that describe the corporate governance of the firm can be used, as Wen (2010) reveals a positive relationship between the pronunciations of the biases and the corporate governance. As for the dependent variables, the ratio between cost and revenue investments is promising for the first hypothesis, and the perceived failure rate of the decision-makers is applicable for the second one. Significantly positive and substantial relationships between the independent and dependent variables would support our findings. The required data has to be gathered from questioning the firm's decision-makers and from archival sources. Overall, we believe that the perceptual perspective on the BVIT is a promising field for future research and that our model constitutes a solid foundation for that purpose.

II.1.6 References

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II.1.7 Appendix

II.1.7.1 Approximation of the Perceived BVIT for Revenue Investments

The perceived BVIT for revenue investments is defined as follows:

$$PV(\tilde{R}) = \sum_{i=1}^n p_i (R_i)^\alpha - (SQ_R)^\alpha \quad (1)$$

Now we replace the revenue outcomes R_i by the sum of the status quo revenues SQ_R and the changes of the status quo revenues for the outcome i .

$$V(R) = \sum_{i=1}^n p_i (SQ_R + \Delta_i SQ_R)^\alpha - (SQ_R)^\alpha \quad (2)$$

where Δ_i indicates the relative changes of the status quo revenues for the outcome i

In a next step, we apply the Taylor Formula to approximate the perceived value for an outcome $(SQ_R + \Delta_i SQ_R)^\alpha$. The Taylor Formula is a mathematical concept for approximating functions of sums. It is defined as follows:

$$f(x+h) = f(x) + f'(x)h + \frac{1}{2}f''(x)h^2 \quad (3)$$

We can apply this concept to approximate the perceived value for a revenue i by setting $x = SQ_R$; $h = \Delta_i SQ_R$.

$$\begin{aligned} f(x) &= f(SQ_R) = (SQ_R)^\alpha \\ f'(x)h &= f'(SQ_R)\Delta_i SQ_R = \alpha(SQ_R)^{\alpha-1}\Delta_i SQ_R = \alpha(SQ_R)^\alpha \Delta_i \\ \frac{1}{2}f''(x)h^2 &= \frac{1}{2}f''(SQ_R)\Delta_i^2 SQ_R^2 = \alpha(\alpha-1)(SQ_R)^{\alpha-2}\Delta_i^2 SQ_R^2 = \frac{1}{2}\alpha(\alpha-1)(SQ_R)^\alpha \Delta_i^2 \end{aligned} \quad (4)$$

$$\rightarrow f(x+h) = (SQ_R + \Delta_i SQ_R)^\alpha \approx (SQ_R)^\alpha + \alpha(SQ_R)^\alpha \Delta_i + \frac{1}{2}\alpha(\alpha-1)(SQ_R)^\alpha \Delta_i^2$$

Reinserting the approximated perceived values, the perceived BVIT of a revenue investment can then be described in the following form:

$$\begin{aligned} PV(\tilde{R}) &\approx \sum_{i=1}^n p_i \left((SQ_R)^\alpha + \alpha(SQ_R)^\alpha \Delta_i + \frac{1}{2}\alpha(\alpha-1)(SQ_R)^\alpha \Delta_i^2 \right) - (SQ_R)^\alpha = \\ &\alpha(SQ_R)^\alpha \left[\sum_{i=1}^n p_i \Delta_i + \frac{1}{2}(\alpha-1) \sum_{i=1}^n p_i \Delta_i^2 \right] = \alpha(SQ_R)^\alpha \left[\mu_R + \frac{1}{2}(\alpha-1) \mu_R^2 + \frac{1}{2}(\alpha-1) \sigma_R^2 \right] \end{aligned} \quad (5)$$

II.1.7.2 Approximation of the Perceived BVIT for Cost Investments

The perceived BVIT for c investments is defined as follows:

$$PV(\tilde{C}) = \sum_{i=1}^n p_i (-\beta(-C_i)^\alpha) + \beta(-SQ_C)^\alpha \quad (6)$$

Again, we describe the cost outcomes C_i as the sum of the status quo costs SQ_C and the changes of the status quo costs for the outcome i .

$$PV(\tilde{C}) = \sum_{i=1}^n p_i (-\beta(-SQ_C + \Delta_i SQ_C)^\alpha) + \beta(-SQ_C)^\alpha \quad (7)$$

where Δ_i indicates the relative changes of the status quo costs for the outcome i

Now we apply again the Taylor Formula to approximate the perceived values for the cost outcome i by inserting $x = SQ_C$; $h = \Delta_i SQ_C$ into the Taylor formula.

$$\begin{aligned} f(x) &= f(SQ_C) = -\beta(-SQ_C)^\alpha \\ f'(x)h &= f'(SQ_C)\Delta_i SQ_C = \beta\alpha(-SQ_C)^{\alpha-1}\Delta_i SQ_C = \beta\alpha(-SQ_C)^\alpha \Delta_i \\ \frac{1}{2}f''(x)h^2 &= \frac{1}{2}f''(SQ_C)\Delta_i^2 SQ_C^2 = -\frac{1}{2}\beta\alpha(\alpha-1)(-SQ_C)^{\alpha-2}\Delta_i^2 SQ_C^2 = -\frac{1}{2}\beta\alpha(\alpha-1)(-SQ_C)^\alpha \Delta_i^2 \\ \rightarrow f(x+h) &= -\beta(-SQ_C - \Delta_i SQ_C)^\alpha \approx -\beta(-SQ_C)^\alpha + \beta\alpha(-SQ_C)^\alpha \Delta_i - \frac{1}{2}\beta\alpha(\alpha-1)(-SQ_C)^\alpha \Delta_i^2 \end{aligned} \quad (8)$$

The perceived BVIT of a cost investment can then be approximated in the following form:

$$\begin{aligned} PV(\tilde{C}) &\approx \sum_{i=1}^n p_i \left(-\beta(-SQ_C)^\alpha + \beta\alpha(-SQ_C)^\alpha \Delta_i - \frac{1}{2}\beta\alpha(\alpha-1)(-SQ_C)^\alpha \Delta_i^2 \right) + \beta(-SQ_C)^\alpha = \\ &\beta\alpha(-SQ_C)^\alpha \left[\sum_{i=1}^n p_i \Delta_i - \frac{1}{2}(\alpha-1) \sum_{i=1}^n p_i \Delta_i^2 \right] = \beta\alpha(-SQ_C)^\alpha \left[\mu_C - \frac{1}{2}(\alpha-1) \mu_C^2 - \frac{1}{2}(\alpha-1) \sigma_C^2 \right] \end{aligned} \quad (9)$$

II.1.7.3 Proof of the Perception Paradox

To mathematically prove the preference for cost investments over revenue investments, we compare the perceived values for two identical investments that differ only in their type. For this constructed case, the perception paradox formulates that the perceived BVIT for a cost investment must be strictly larger than the perceived value of an identical investment on the revenue side ($PV(\tilde{R}) < PV(\tilde{C})$). The investment identity is established by the equality of the status quo payments in absolute terms ($SQ_R = -SQ_C = SQ$) and the equality of the first two moments of the effect distribution ($\mu_R = \mu_C = \mu \wedge \sigma_R^2 = \sigma_C^2 = \sigma^2$):

$$PV(\tilde{R}) < PV(\tilde{C}) \text{ for } SQ_R = -SQ_C = SQ \bigwedge \mu_R = \mu_C = \mu \bigwedge \sigma_R^2 = \sigma_C^2 = \sigma^2 \quad (10)$$

By inserting the identical values into the perceived value functions for cost and revenue investments, inequality (10) can be rewritten:

$$\begin{aligned}
\alpha(SQ)^\alpha \left[\mu + \frac{1}{2}(\alpha - 1)\mu^2 + \frac{1}{2}(\alpha - 1)\sigma^2 \right] &< \beta\alpha(SQ)^\alpha \left[\mu - \frac{1}{2}(\alpha - 1)\mu^2 - \frac{1}{2}(\alpha - 1)\sigma^2 \right] \\
\left[\mu + \frac{1}{2}(\alpha - 1)\mu^2 + \frac{1}{2}(\alpha - 1)\sigma^2 \right] &< \beta \left[\mu - \frac{1}{2}(\alpha - 1)\mu^2 - \frac{1}{2}(\alpha - 1)\sigma^2 \right] \\
0 < \beta\mu - \frac{1}{2}\beta(\alpha - 1)\mu^2 - \frac{1}{2}\beta(\alpha - 1)\sigma^2 - \mu - \frac{1}{2}(\alpha - 1)\mu^2 - \frac{1}{2}(\alpha - 1)\sigma^2 & \quad (11) \\
0 < (\beta - 1)\mu - \frac{1}{2}(\beta + 1)(\alpha - 1)\mu^2 - \frac{1}{2}(\beta + 1)(\alpha - 1)\sigma^2 \\
0 < (\beta - 1)\mu + \frac{1}{2}(\beta + 1)(1 - \alpha)\mu^2 + \frac{1}{2}(\beta + 1)(1 - \alpha)\sigma^2
\end{aligned}$$

In the next step we show that the three summands of inequality (11) are strictly positive to prove the perception paradox.

$$(\beta + 1)(1 - \alpha)\sigma^2 > 0 \quad (12)$$

The variance of the relative performance effects σ^2 is per definition strictly positive. As the concept of loss aversion requires values of β strictly larger than one, $(\beta + 1)$ is also positive. The parameter conditions for asymmetric risk attitudes require values of α between zero and one, which means that the factor $(1 - \alpha)$ is positive as well. As all three factors are positive, inequality (12) holds strictly true.

$$(\beta + 1)(1 - \alpha)\mu^2 > 0 \quad (13)$$

The same argumentation holds true for inequality (13). The squared expected performance effects μ^2 are positive per definition and the parameter conditions for loss aversion and asymmetric risk attitudes ensure that the complete inequality holds always true.

$$(\beta - 1)\mu > 0 \quad (14)$$

As loss aversion demands values for β larger than 1, the first factor $(\beta - 1)$ is strictly positive. That means that the perception paradox holds for IT investments with positive expected value effects. This condition is probably fulfilled in reality. This condition is probably fulfilled in reality. In general, high-level executives make IT decisions based on proposals from the IT department; moreover, the IT department is unlikely to propose investment opportunities with negative business cases to the senior executives (Tallon et al. 2001). Therefore, we can state that the behavioral effects of loss aversion and asymmetric risk attitudes are at least in combination with other explanations responsible for the perception paradox.

II.1.7.4 Proof of the Productivity Paradox

The overvaluation of IT investments respectively the risk-seeking value perception can be illustrated mathematically by showing that the first derivative of the perceived value function with respect to the variance is strictly positive.

$$\frac{\partial PV(\tilde{C})}{\partial \sigma_c^2} = -\frac{1}{2}\beta\alpha(\alpha - 1)(-SQ_C)^\alpha > 0 \quad (15)$$

$$\beta\alpha(1 - \alpha)(-SQ_C)^\alpha > 0$$

In the next step we show that the four factors of inequality (15) are strictly positive to prove the new productivity paradox. The concept of loss aversion requires values of β larger than 1 and therefore a strictly positive value range for that parameter. The parameter conditions for asymmetric risk attitudes require values of α between zero and one, which means that the parameter α and the factor $(1 - \alpha)$ are positive as well. As the factor $(-SQ_C)^\alpha$ is a power function and as power functions show strictly positive values ranges, the factor is also positive. The argumentation illustrates that all four factors are positive and that inequality (15) holds strictly true. Therefore, we can state that the behavioral effects of asymmetric risk attitudes and loss aversion are at least in combination with other explanations responsible for the overvaluation of risky IT investments. Moreover, the overvaluation even accelerates for more risky IT investments.

III Normative Guidance on IS Decisions – How to Evaluate Investments in Big Data Analytics

III.1 The Integration of the 5th Dimension - A Quantitative Framework on the Business Value of Big Data Analytics”

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Abstract:

Many organizations envision fine-tuning their operational performance and extending their corporate knowledge base toward an insight-driven organization through big data analytics (BDA). However, it is nearly impossible to measure these promises, and therefore, to establish a proper transformation path toward a functioning system. This manuscript develops an analytical model to support organizations in evaluating BDA, and investigates the economic mechanisms of value creation. As fundamental paradigm, we take the perspective on information use and derive business values (BVs) for data-driven actions and decisions. We then adjust for the technological characteristics of volume, veracity, velocity, and variety in a sound and rigorous way by using established scientific approaches. Our evaluation involves reporting on the insights we gained through applying our model to the telematics system in a large German insurance organization. Overall, we provide a theory-based understanding of BDA value creation, and concrete guidance on how to assess BDA's BV

III.1.1 Introduction

Big data analytics (BDA) promises to uncover hidden knowledge, improve decision-making, and provide highly customized services [97]. Thereby, *big data* (BD) represents a high data volume, collected frequently from a variety of data sources with various formats [5], while *analytics* implies the intelligence to utilize and transform BD into knowledge and intelligence [72]. Undeniably, BDA will have a significant, disruptive impact on traditional business models throughout the economy [16, 18, 86]; the volume of available data in the *sensing enterprise*, in which *dumb* physical objects evolve into smart products that collect and share data, is expected to increase tenfold within a few years [94]. Similarly, current market forecasts project data-driven businesses to exceed 260 billion dollars [36]. Considering the high expectations, it is no surprise that BDA is a high priority in recent, current, and future chief information officers' agendas [37, 62]. However, in observing practical reality, organizations often struggle with BDA's basics [16, 58, 67]. Enormous technology investments in mass data storage and high speed computing do not necessarily create business value (BV), as the intended transformation toward a sensing, data- and hence, insight-driven organization requires a long-term evolution with many obstacles and human resistances to overcome [11, 15, 25]. As a key challenge, BDA initiatives require the ex-ante evaluation of their business impact [9]. Thus, a deep, practical need exists for concrete guidance as to how to determine BDA's BV.

The information systems (IS) literature follows two research streams regarding BDA transformation projects: the technological stream focuses on the development from business intelligence to BDA and the respective data architectures, processing capabilities, and analytics tools (e.g., in-memory databases, the MapReduce algorithm, or predictive analytics) [cf. 1, 34, 50]. The economic stream investigates how to evaluate, decide upon, and manage BDA projects [cf. 7, 16]. Thus, the economic stream at best provides the required metrics and objective functions to quantify the value potential, subject to the technological stream's restrictions and requirements. However, whereas academia and practice have continuously enhanced the technological stream [12, 17], the economic lens as to how the *four Vs* of BD (*volume*, *variety*, *velocity*, and *veracity*) translate into BV is comparably underrepresented [63, 102]. Scholars in BDA literature agree that BDA significantly improves organizations' productivity and competitiveness [16, 58, 63] and introduce *value* as the *fifth V* of BD. However, they assign BDA's BV primarily to the sizes of analyzed data sets [34, 97] in terms of *volume* while neglecting the other *three Vs*.

Consequently, they miss a sound evaluation of BDA benefits based on the technological development. Thus, we formulate the following research question:

How can organizations determine BDA's BV, considering the technological characteristics of volume, variety, velocity, and veracity?

To answer the research question and support organizations in evaluating BDA initiatives, this paper derives an analytical model. The primary challenge inherent to this research objective is that BDA does not translate into BV, per se, and that the generated impact is mostly intangible. However, BDA constitutes a basis for better decisions and actions, which can sequentially create BV [1]. Thus, we switch perspectives from BDA's intangible impact to the tangible evaluation of *information use*, first deriving the BV of the actions and decisions that BDA inspires [90]. Second, we adjust purely economic considerations for the technological characteristics of the *four Vs*. Therefore, we follow a modular model setup by stepwise integrating the value of imperfect information proposed by Stratonovich [90] for *volume* and *veracity*, the value-time curve by Hackathorn [40] for *velocity*, and portfolio theory by Markowitz [65] for *variety*. We finally integrate these various BDA characteristics drawing on value-based management (VBM) with its ability to translate a real-world object's different dimensions into economic effects on the organizational level as common valuation basis [13].

Overall, we contribute to literature by filling the gap of missing guidance as to how to quantify BDA's BV. As research paradigm, this paper follows design science research (DSR): First, design objectives are derived from justificatory literature on BDA's technological and economic aspects in Section 2 and 3. Subsequently, in Section 4, the development and specification of the model as DSR artifact is outlined. Thereby, we follow the work of Cohon [19] and combine normative analytical modeling and VBM as justificatory knowledge to develop a quantitative model for determining BDA's BV. Section 5 reports on the evaluation against the stated design objectives, and discusses the insights we gained in applying our model to the real-world problem of insurance telematics. Section 6 concludes by summarizing our key results, and discussing both limitations and aspects for further research.

III.1.2 Background

III.1.2.1 Techno-economic Development of Big Data Analytics

Basically, BDA is an outcome of the last decades' techno-economic development, and originated from the interplay between technological progress and business necessity.

Starting with the first wave of data growth in the 1970s, the business side proposed the first data-centric management approaches, while the technological side developed the fundamentals for *business intelligence* (BI) [14, 93, 98]. As a major innovation, BI tools (e.g., data warehousing or online analytical processing) initially enabled the aggregation and harmonization of heterogenic, transactional data into one unified analytical database system and facilitated simple data mining in these databases. Hence, BI discovered new information by enabling and understanding connected data, deducing trends, and making corporate knowledge interpersonally retrievable. As a result, organizations that could utilize BI tools' potential often gained competitive advantages by improving their strategic, and business relevant decisions [17]. However, the knowledge (e.g., customer insights) remained exclusively within an organization or its networks' structures [15].

According to Chen et al. [17], the second wave of data growth originated in the early 2000s, and began with Web 1.0 technologies (e.g., search engines or e-commerce platforms), which led to the more user-centric Web 2.0. Unstructured data became available from both social networks and user-generated content. This wave radically propelled the business world toward digital competition [17]. Customer knowledge and attraction were no longer bound to personal contacts with an organization, but were rooted in the possession of data. New industry leaders, e.g., Amazon or Facebook, leveraged internet users' data footprints, began to know their customers even before any initial contact, and could provide recommendations to their customers that they did not yet realize they needed [26].

Business digitalization further accelerates with the current third wave of data growth, caused by smartphones and ubiquitous computing [17, 34]. The substantial amount of objects that continuously connect to the internet increase data volume to an enormous extent [17]. Experts estimate continuing data volume growth, from 4.4 trillion gigabytes in 2014 to 44 trillion in 2020 [46, 96]. As a technological solution, BDA enables the analysis of such a huge data volume, with a high proportion of unstructured data, in a short time [16, 34]. As a proper economic reaction, organizations must now develop BDA capabilities to avoid losing their customers to better informed competitors. However, from a BV perspective, large data volumes suffer from low information-density. Hence, the relative data value continuously decreases, and only its high volume makes BDA profitable [34]. Thus, organizations face a challenge in finding new competitive positions, and in making the appropriate technological decisions.

III.1.2.2 Technological Basis of Big Data Analytics

Regarding its technological basis, BDA can be decomposed into *big data* and *analytics*. Definitions for BD vary, and have evolved over time [cf. 80], but a generally accepted framework [cf. 17, 38, 55, 69, 91] stems from Laney [57], who defines BD along *three Vs*:

Volume defines BD using a scale of stored data. However, it is difficult to establish a fixed magnitude to define BD, as both data storage capacities and data availability continuously evolve. Whereas one terabyte is an accepted threshold in practice [82], scholars typically consider higher volumes of multiple petabytes [34]. The decisive volume exceeds processing capabilities of relational databases, and requires such new tools as NoSQL or MapReduce [34].

Variety defines BD by the different data types and their corresponding degree of structuring. As only 5% of existing data is structured (e.g., data stored in relational databases) [22], the majority of data is semi-structured (e.g., Extensible Markup Language documents, email, JavaScript Object Notation), or even unstructured (e.g., images, audio, videos) and therefore, not organized for machine-based analyses, per se. Thus, as this is intensified by the radically increasing share of unstructured data from sources as social media or the *Internet of Things*, data variety represents a challenge to acceptable processing times. Additionally, new unstructured data sources continuously emerge, and must be considered in corporate decision-making. For example, biometric data can identify different types of customers, and this can be used to analyze buying behaviors and determine cross-selling opportunities [17, 34].

Velocity defines BD relative to the rising frequency of both generated data and processing speed. To exploit its total benefits, IS must parallel this acceleration; for example, consider the increasing dissemination of mobile devices with GPS receivers that enables *location-based services*. Organizations can process the generated data to propose individual offers to their customers during their shopping experiences. However, as customers move on, slow data processing would result in late offers without any benefits. BD technologies (e.g., in-memory databases) can respond by forming a basis for required real-time analytics [17, 34].

With the increase in use of Laney's [57] *three Vs* and the decrease of information-density, the *veracity* of data blurs developed as a *fourth V* to define BD [5, 28, 34, 35, 39, 82]:

Veracity defines BD through the trustworthiness of uncertain and inaccurate data. With the increasing importance and growth of external data sources, data trustworthiness varies more than in exclusive internal data sources. For example, consider customer opinions from

YouTube videos or Amazon reviews. Their contents are subjective and possibly highly biased, and consequently, these new data sources may not be completely trustworthy. Nevertheless, they might still provide valuable information, and should be considered in decision-making. The BD toolset responds by providing optimization algorithms (e.g., robust or stochastic optimizations) that can handle these kinds of data, to a certain extent [51].

Besides, with changes in data types, sources, and characteristics, the *analytics* requirements also change. Even if an organization can handle the *four Vs* in collecting and storing data, its mere availability does not improve decision-making processes. Organizations can only gain insights and knowledge from BD by applying analytical techniques [34]. Thus, academia distinguishes between various types of tools depending on the data they process [17]. Multimedia analytics summarizes all techniques related to all types of media content, or specifically audio, images, or video. Text analytics aims to extract information from structured and semi-structured textual data (e.g., emails, blogs, news feeds, organizational reports, or surveys) by using such tools as summarization techniques, question answering, or sentiment analysis [34]. These tools are also partially applicable to semi-structured or unstructured data from audio, images, and video by preprocessing them with text transcription algorithms [34]. A further class of analytics tools (e.g., social media analytics, network analytics, or mobile analytics) extends further content-based analyses of multimedia analytics through structure-based analyses [34]. These extract users' information regarding their relationships and usage behaviors using techniques like community detection, social influence analysis, and link prediction [34]. Finally, predictive analytics subsumes techniques that predict future developments, trends, and outcomes. For a more detailed overview on analytics, we refer to [17, 34].

III.1.2.3 Business Value of Big Data Analytics

Despite its technological potential, BDA must still answer if and how it can translate into BV from an economic perspective. First, data is a set of signs or symbols resulting from object properties and events [2]. Data can only convert to information or knowledge through semantic analysis or contextualization, respectively, which may then transform into competitive advantage [2, 30, 92]. As a key prerequisite, the final transformation of knowledge into BV only occurs if organizations actively use their knowledge, understand to gain competence and take appropriate actions in terms of intelligence [2, 58].

In general, the technological basis of information technology (IT) does not deliver value, *per se* [10, 43, 54]. The benefits of IT investments typically originate from organizational change, e.g., when IT enables individuals to perform tasks better and do things differently [73]. According to Melville et al. [70], IT's BV is derived from "the organizational performance impacts of information technology, at both the intermediate process level and the organization-wide level, and comprising both efficiency impacts and competitive impacts." However, owing to this indirectness, IT evaluation remains a challenge in IT decision-making [33]. As early as the 1980s and early 1990s, many studies examined IT value creation, but failed to provide evidence of a positive relationship between IT investments and productivity growth in the United States economy [42]. Finally, the debates regarding IT advanced and slow productivity growth resulted in the *productivity paradox* [9]. Nowadays, academia and practice agree on the existence of IT's BV [44, 52]. Nevertheless, two significant concerns still exist regarding IT evaluation and IT decision-making: First, failures in IT investments often result from biases in both value perceptions and IT decision-making [9, 74]. Thus, management decisions may focus on cost-reducing alternatives, and neglect those that promise additional revenue [3]. Moreover, according to Anderson et al.'s [4] new productivity paradox, decision-makers tend to overestimate IT's BV [27]. Second, evaluations of IT investments struggle with intangible value effects. Although tangible benefits (e.g., cost reductions) are typically observable, intangible benefits can only be indirectly measured [48, 60, 78, 87]. However, a sound valuation of IT investments requires holistic consideration of tangible and intangible benefits [47, 84, 100]. Thus, the formulation of objective, quantitative models for determining IT's BV is crucial to support decision-makers, and to abolish or support their feelings as decision bases.

As answer to this challenge from a BD and BDA perspective, scholars in BDA literature introduced *value* as the *fifth V* of BD, and assign BDA's BV potential primarily to the sizes of analyzed data sets [34, 97]. Thereby, it is widely accepted that BD and BDA significantly improve organizations' productivity and competitiveness [16, 58, 63]. Besides, Williams and Williams [101] propose a five step model in a BI context, to determine BI's BV in terms of increasing after-tax cash flows, and Popovic et al. [75] provide a conceptual model to evaluate the BI's BV in terms of business performance resulting in increasing information quality. Nevertheless, the economic stream still faces the challenge to go behind the technological base and to translate the intangible BD and BDA benefits into tangible benefits in terms of *information use* [1, 90]. Although the technological basis for BDA provides the ability to discover knowledge and use it for predictions, this may result in blind

action without intelligent decision-making, and thus, without any competitive advantage [79].

III.1.3 Justification and Design Objectives

In order to justify the research topic as a meaningful DSR problem (EVAL 1), we manifest the problem observed in academia and practice in design objectives and refer to justificatory prescriptive knowledge that guide the design of our solution approach.

Preventing a second productivity paradox for BDA strongly requires the quantitative analysis of BDA's BV. This analysis should consider parallels to classical IT projects, as well as the BDA's particularities. While classical IT projects typically require ex-ante, one-time investment decisions, BDA initiatives additionally necessitate continuous decisions regarding new data acquisitions, adaptation of new technologies, and the development or adjustment of algorithms. Furthermore, the *four Vs*, which embody technological innovation, must be translated into BV. Therefore, we derive the following design objectives as a condensate of the current state of literature (Section 2):

(O.1) *Practicability*: A proper DSR artifact should be applicable in practice and support the evaluation of BDA.

(O.2) *Consideration of BD particularities*: A proper DSR artifact should consider the technological characteristics of BD's *four Vs*: *volume*, *variety*, *velocity*, and *veracity*.

(O.3) *Objectivity*: A proper DSR artifact should quantitatively and objectively assess BDA's BV, analogous to other IT projects, with respect to an organization's value.

For designing such a proper DSR artifact, we refer to VBM and normative analytical modeling as justificatory knowledge. Normative analytical modeling compiles the primary components of an economic problem into mathematical equations to deduct prescriptive results and to enhance its interpretability and comprehensiveness [71], while VBM assists in achieving such a compilation explicitly for value contributions [13].

Further, VBM has been recently successfully applied for decision problems in both academia and practice [13]. It concentrates on the long-term development of an organization's value and investigates all activities and decisions regarding their contributions to this long-term value [49, 53]. Thus, VBM enhances the shareholder value approach [24] initially introduced by Rappaport [77], and elaborated upon by Copeland et al. [20] and Stewart and Stern [89]. Essentially, VBM establishes three key requirements to quantify an organization's value on an aggregated level; the value contributions of

individual assets and decisions must be based on: (1) cash flow effects, (2) the time value of money, and (3) the decision-maker's risk attitude [13]. The corresponding valuation functions (e.g., the risk-adjusted net present value (NPV) that meet all requirements usually originate from investment and decision theories [13, 23].

III.1.4 Artifact Description

III.1.4.1 Basic Idea

When assessing BDA's BV, we switch perspectives from BDA's generated intangible impact to the tangible evaluation of *information use* as our guiding principle. Thus, we do not consider data or information as a vague basis for better decisions and actions, but rather, we focus on the BV created by inspired tangible responses. This change in perspectives enables us to monetize and quantify BDA's economic impact. Completing the techno-economic picture, the BV of induced actions and decisions is adjusted for BDA's technological constraints and characteristics. Ultimately, the value contributions are aggregated over all inspired actions and decisions to derive BDA's BV. Figure 1 illustrates the idea of information use.

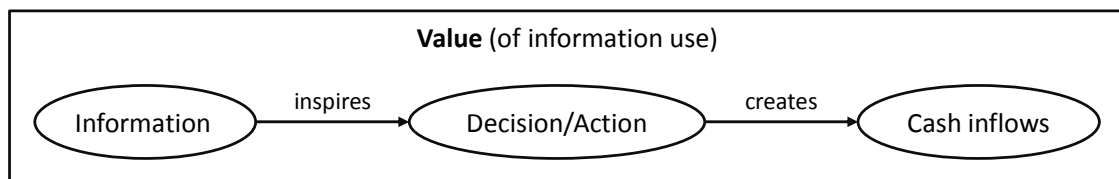


Figure 1. The Idea of the Fifth BD Dimension Value (of Information Use)

In order to switch perspectives to the more concrete level of information use, we begin by decomposing BDA's BV into single occurrences of information as its atomic elements. Thereby, we can reduce complexity to a comprehensible extend according to design objective (O.1). The analysis of such a single occurrence of information (e.g., the signal of a fire alarm station) enables defining this information's economic benefit as cash inflows generated by a consequential action (e.g., in-time arrival of fire department). Hence, the more often the information occurs, the more often the induced action can generate cash inflows. In other words, the BV scales with the technological dimension of *volume*, in terms of the number of information occurrences. However, information occurrence can only inspire valuable actions if the underlying information system observes the information and transforms it into a decision. Thus, the quality of the underlying information system determines whether information can be transferred into BV. Following this interpretation, *veracity* is the quality of an information system in capturing and analyzing the focal

information. This basic idea is also the essential of Stratonovich's [90] value of imperfect information. Further pursuing the idea of *information use*, information speed, or *velocity*, is defined as the time elapsed from information occurrence to the implementation of its consequences. According to Hackathorn [40] and White [99], an information's value exponentially decreases with longer latencies, and accordingly, BDA's BV must also be discounted for *velocity*. However, even if an organization implements a high quality database and a fast processing system for high data volume, different information may still simultaneously occur and inspire the same action. Even worse, no information may occur. Hence, no constant provision of decision support exists, which in turn exposes organizations to risk. Therefore, we consider *variety* to broaden the perspective from a single information source to an organization's information portfolio. *Variety* thereby refers to interdependencies within the information portfolio, and higher diversity promises more balanced provision of information. Therefore, we construct the organization's information portfolio following Markowitz's portfolio theory [65]. Figure 2 summarizes our basic idea.

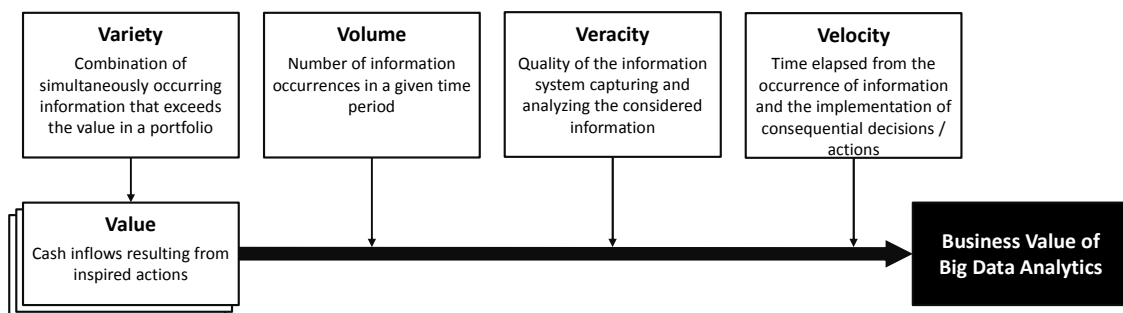


Figure 2. Basic Idea

III.1.4.2 Information Cash Flows

Beginning on the lowest aggregation level, we model cash flows CF_I resulting from a single use of single information I . Therefore, we divide a planning period t into mutually exclusive information periods, and define an information period as an infinitely small period of time, in which information can occur only once. This complexity-reducing approach is often used in revenue management in the context of airline tariffs, in which only one single booking inquiry (i.e., the information) can occur in an information period [cf. 61]. Information occurrences in each information period follow a binomial logic with probability p_I . If the information does not occur ($1 - p_I$), this also does not trigger the valuable action, and consequentially, this does not create any cash inflows. If the information occurs (p_I), the underlying system must be able to observe occurrence, derive the correct interpretation, and define the appropriate consequences to finally translate information into cash inflows.

Correspondingly, we define information quality or *veracity* q_I as the fraction of information occurrences detected by the underlying BDA system and generating the desired cash flows of information CF_I . Figure 3 illustrates this mechanism of an information's value as a decision tree, inspired by Stratonovich's [90] value of imperfect information.

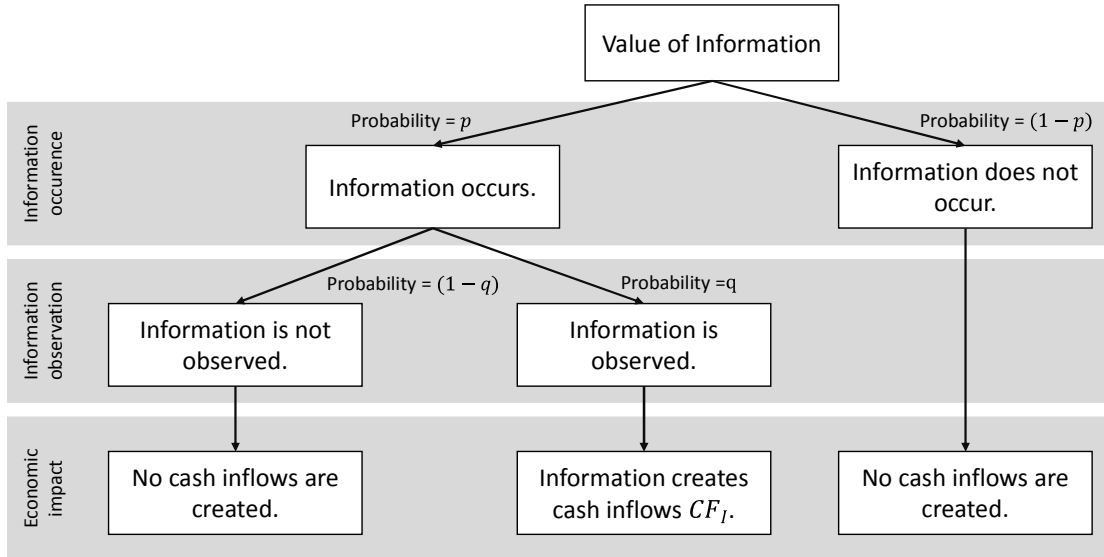


Figure 3. The Decision Model for Information Value

An analysis of our decision tree reveals that we can derive the expected value of information $E[V(I)]$ by multiplying the cash inflows of information and their corresponding branch probabilities. The variance $VAR[V(I)]$ can be calculated accordingly.

$$E[V(I)] = p_I \cdot q_I \cdot CF_I + (1 - p_I) \cdot 0 + p_I \cdot (1 - q_I) \cdot 0 = p_I \cdot q_I \cdot CF_I$$

$$\begin{aligned} VAR[V(I)] &= p_I \cdot q_I \cdot CF_I^2 + (1 - p_I) \cdot 0 + p_I \cdot (1 - q_I) \cdot 0 - p_I^2 \cdot q_I^2 \cdot CF_I^2 \\ &= p_I \cdot q_I \cdot (1 - p_I \cdot q_I) \cdot CF_I^2 \end{aligned} \quad (1)$$

III.1.4.3 Time Value of Information Cash Flows

At this point, our basic decision tree demonstrates that information's value manifests in superior corporate decisions or actions, and this ultimately translates into cash flows. However, we implicitly assumed real-time information processing, as we do not yet consider decision and information latencies (*velocity*). Hackathorn [40] and White [99] highlight that the value of information decreases convexly with increasing information time (property (P.1)). Thereby, information time t is the total time elapsed until an information-induced action or decision is implemented, and comprises observation, processing, decision, and implementation latencies [40]. In today's dynamic times, the appropriate decisions and windows of opportunity might only exist for a few seconds of *value time* (t_I^{MAX}) as upper

limit for information time (P.2). Information-induced actions or decisions must be implemented within the *value time* to create considerable value (above a relevance threshold K). Otherwise, decisions and actions result from outdated information, and do not have any impact. Consequently, time value of information ($TV(I)$) is maximal when the underlying decision is implemented in real time (P.3). In this case, the information time equals zero ($t_I = 0$). The information system immediately analyzes information and implements the corresponding consequence. The value of information from the basic decision tree then represents the realized economic impact.

Mathematically, the relationship between time and BV can be expressed by a value-time curve, which exponentially declines from its maximum in time zero to a negligibly small threshold in the *value time* ($0 \leq t_I < t_I^{\text{MAX}}$). Figure 4 illustrates its schematic course and the three key properties of the time value of information.

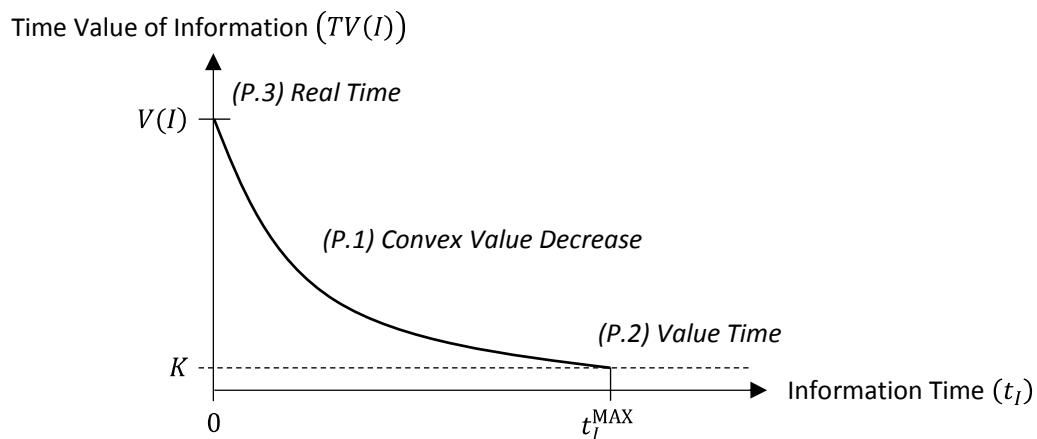


Figure 4. Mathematical Properties of the Time Value of Information

A structural analogy, extending the value of information to the time value of information, can be drawn to the decay law of radioactive elements in the natural sciences. This chemical-physical principle describes the reduction of radioactive substances over time. The amount of substance at the beginning of the observation period is maximal, analogous to the real-time value of $TV(I)$ (P.3). The amount of substance in the observation period then decreases convexly, with a constant decay rate λ_I . This exponential decay is structurally equivalent to the first property of $TV(I)$ (P.1). Therefore, we transfer the decay law of radioactive elements to the $TV(I)$ in Equation (2):

$$TV(I) = V(I) \cdot \exp(-\lambda_I \cdot t_I) \quad (2)$$

Calculating the decay rate requires a second observation of the available relative amount of substance $\bar{\delta}$ at a specific time. For our purpose, we choose value time ($t_I = t_I^{\text{MAX}}$) and the corresponding value threshold ($K_I = \delta_I \cdot V(I)$) as referential observations (P.2). Equation (3) illustrates the calculation of the decay rate for $TV(I)$:

$$\lambda_I = -\frac{\ln(\delta_I)}{t_I^{\text{MAX}}} \quad (3)$$

Finally, we include the decay factor to Equation (1), and derive the expected $TV(I)$ and its variance. Due to the variance's quadratic properties, we scale it with a quadratic decay factor:

$$\begin{aligned} E[TV(I)] &= E[V(I)] \cdot \exp\left(\frac{\ln(\delta_I) t_I}{t_I^{\text{MAX}}}\right) = p_I \cdot q_I \cdot CF_I \cdot \exp\left(\frac{\ln(\delta_I) t_I}{t_I^{\text{MAX}}}\right) \\ VAR[TV(I)] &= VAR[V(I)] \cdot \exp\left(\frac{2\ln(\delta_I) t_I}{t_I^{\text{MAX}}}\right) = p_I \cdot q_I \cdot (1 - p_I \cdot q_I) \cdot CF_I^2 \cdot \exp\left(\frac{2\ln(\delta_I) t_I}{t_I^{\text{MAX}}}\right) \end{aligned} \quad (4)$$

III.1.4.4 Application of VBM

We subsequently aggregate from this most concrete level of information use over the complete planning horizon (timely aggregation of value events). We start with the $TV(I)$'s sum over the information periods in a single planning period n to aggregate our results to the next level of planning periods. Then, in line with the *central limit theorem* as a mathematical principle, the sum of n identically and independently distributed random variables, with expected values μ and variances σ^2 , follows a normal distribution, with mean $n \cdot \mu$ and variance $n \cdot \sigma^2$. As we consider information periods as very short time periods, our model fulfills the precondition that the decision tree is constant across all information periods.

As a next step, we then account for further time-aggregation by adding all periodic cash flows (of information) over all planning periods as a central evaluation basis for VBM. Thus, we incorporate the time value of money according to VBM, using the present value (PV) as a valuation function. The PV discounts the cash flows generated in each planning period to the beginning of the planning horizon, analogous to the discounting logic of the NPV [13], but abstracts from investment outflows. This is reasonable, as we explicitly aim for BDA's benefits. The discounting logic finally results in multiplying periodic cash flows with the discount factor $\Delta_\mu = 1/r$, with r denoting the risk-free interest rate, for the expected value, and $\Delta_{\sigma^2} = 1/(2+r)r$ for the variance [29] if the planning horizon is sufficiently

large. The relevant decision criteria (i.e., the expected present value of information $E[PV(I)]$, its variance $VAR[PV(I)]$, and its standard deviation $STD[PV(I)]$) then equal:

$$\begin{aligned}
 E[PV(I)] &= \Delta_{\mu} \cdot n \cdot p_I \cdot q_I \cdot CF_I \cdot \exp\left(\frac{\ln(\delta_I) t_I}{t_I^{\text{MAX}}}\right) \\
 VAR[PV(I)] &= \Delta_{\sigma^2} \cdot n \cdot p_I \cdot q_I \cdot (1 - p_I \cdot q_I) \cdot CF_I^2 \cdot \exp\left(\frac{2\ln(\delta_I) t_I}{t_I^{\text{MAX}}}\right) \\
 STD[PV(I)] &= \sqrt{\Delta_{\sigma^2} \cdot n \cdot p_I \cdot q_I \cdot (1 - p_I \cdot q_I)} \cdot CF_I \cdot \exp\left(\frac{\ln(\delta_I) t_I}{t_I^{\text{MAX}}}\right)
 \end{aligned} \tag{5}$$

III.1.4.5 Information Portfolio

After conducting time-aggregations, we now consider multiple information sources (volume aggregation), and integrate *variety*. For this, we use portfolio theory established by Markowitz [65]. As financial portfolio theory aims to construct assets' optimal risk-return portfolios, we similarly aim for optimal risk-return data portfolios. Thereby, the present values' normal distributions fulfill the central assumption of classical portfolio theory. However, whereas financial portfolios intend to improve returns by weighting assets, in our conceptualization of BV, where information triggers valuable actions, it is impossible to use some information more than others. Therefore, the portfolio idea involves whether to use single information. Correspondingly, we consider the unweighted portfolio value, in which each piece of information has an equal relative contribution as a proper valuation basis. Accordingly, we define BDA's BV as the average value of the information portfolio, consisting of m information sources:

$$\begin{aligned}
 E[BDA] &= \frac{1}{m} \sum_{I=1}^m E[PV(I)] \\
 VAR[BDA] &= \frac{1}{m^2} \sum_{I=1}^m \sum_{J=1}^m \rho_{I,J} \cdot STD[PV(I)] \cdot STD[PV(J)]
 \end{aligned} \tag{6}$$

On this highest BDA level, interdependencies between single data sources become relevant. Mathematically, we reflect these interdependencies by the correlation coefficient $\rho_{I,J}$. Generally, correlation coefficients indicate whether two random variables behave rather similarly (positive correlation) or contrarily (negative correlation). Considering the underlying information decision trees as atomic ingredients of the BDA's ultimate BV, its randomness stems from two initial steps: information occurrence (p_I) and observation (q_I). Thus, correlation coefficients indicate whether information tends to occur simultaneously or

in different information periods. While investors add low correlated assets for stable investment returns, organizations can add low correlated data to their BDA system to achieve constant *informativeness* (i.e., a constant provision of valuable information). Diversified information portfolios ensure that the BDA system provides continuous supply, and steadily triggers proper actions. Undiversified information portfolios, in contrast, sometimes create high value, but sometimes do not create any value at all.

Whether organizations prefer more stable or more extreme informativeness depends on their risk attitudes. We consider the risk attitude by the VBM certainty equivalent method. Therefore, BDA's expected BV and its variance must be inserted in the so called μ - σ -preference function to derive BDA's ultimate BV expression, as shown in Equation (7):

$$\begin{aligned} V(BDA) &= E[BDA] - \frac{\alpha}{2} \cdot VAR[BDA] = \\ &= \frac{1}{m} \sum_{I=1}^m E[PV(I)] - \frac{\alpha}{2} \cdot \frac{1}{m^2} \sum_{I=1}^m \sum_{J=1}^m \rho_{I,J} \cdot STD[PV(I)] \cdot STD[PV(I)] \end{aligned} \quad (7)$$

Table 1 summarizes our results by describing the BV logic inherent to the basic dimensions of BDA, and illustrates the model construct, which resembles the respective dimension, and outlines the knowledge that justifies their implementations.

	Business Value Logic	Model Construct	Justificatory Knowledge
Volume	The more frequently the BDA system delivers insights, the more often the responsive action generates cash inflows.	$n \cdot p_I$	Stratonovich [90]
Veracity	The higher the fraction of potential information observed by the BDA system, the more often the valuable action can be triggered.	q_I	Stratonovich [90]
Velocity	The faster a BDA system processes information in relation to value time, the higher the BV created.	$\exp\left(\frac{\ln(\delta_I) t_I}{t_I^{MAX}}\right)$	Hackathorn [40] White [99]
Variety	The more balanced the processed information portfolio is in terms of structured and unstructured data, the more constant the provided informativeness, and the higher the created BV.	$\rho_{I,J}$	Markowitz [65]
Value	The more profitable the triggered action, the higher the created BV.	CF_I	Stratonovich [90]

Table 1: BV Logic for the Basic Dimensions of BDA

III.1.5 Evaluation

We follow the framework of Sonnenberg and vom Brocke [88] to demonstrate and evaluate our value model. They suggest a combination of ex-ante/ex-post and artificial/naturalistic evaluations [76, 95] in four different evaluation activities: EVAL1 to EVAL4. EVAL1 demands the presentation of the research topic as a meaningful DSR problem, and the

formulation of design objectives; EVAL2 demands the validation of design specifications against design objectives; EVAL3 aims to validate instantiation. In the final step, EVAL4 strives to validate usefulness and applicability in real-world settings.

As we already met the EVAL1 requirements in Sections 1, 2, and 3, we continue with an evaluation as to whether our model properly covers the motivated research problem (EVAL 2) in Section 5.1. Therefore, we discuss its design specification against the design objectives deduced from justificatory literature [83]. Regarding EVAL3, we implemented a prototype of our model in Microsoft Excel. We then applied our prototype to a technological BDA decision problem, in the insurance telematics context for EVAL4 (Section 5.2). We report on the insights relative to the corresponding evaluation criteria (e.g., effectiveness and efficiency, and impact on user [64]) in Section 5.3.

III.1.5.1 Validation of the Design Specifications and Applicable Adjustments

Regarding design objective (O.2), the model integrates BD's *four Vs* by compiling their technological features into economic effects (see Table 1). Whereas *volume* and *veracity* reflect how often information can propagate into value, *velocity* determines absolute value by discounting for long latencies. *Variety* covers the relationships between various pieces of information, and assigns a higher BV if the information portfolio is more diversified, ensuring more constant informativeness. The designed artifact initially implements the effects of BDA stepwise, and finally integrates them into an overarching value function that follows VBM principles. Our multi-dimensional model uses the BV contributions of the *four Vs* as a valuation basis, and is also compliant with design objective (O.3).

An analysis of usability and applicability in practice (O.1.) reveals that our value function is flexible, and fits multiple contexts. An interview with the Head of Big Data (HBD) from a large German insurance organization led us to jointly identify the *in-depth value analysis of single information* and the *strategic prioritization of the four Vs* as two important application domains. The HBD reported that, regarding the first domain, his team often faces a problem in that their analytics machine generates many significant patterns and evidence, and they struggle to identify the valuable patterns to be integrated in their policy making process. Accordingly, the HBD assesses the separate evaluation of data patterns and their implications as highly relevant. Applying our model to the strategic prioritization of the *four Vs* addresses the practical issue that organizations cannot radically establish a mature BDA system in a single step, but that they must follow a reasonable evolution. Thus, organizations again require a thoughtful prioritization of what dimensions to first evolve. Although our

model can cover these problems, it requires many input parameters that must be estimated beforehand. Therefore, we enhance our model's usability in these two contexts by proposing two less complex representations of our value function, which are explicitly tailored to these primary problems.

Adjustment for Detailed Analysis of Single Information

First, we can reduce our value function for a detailed analysis of single information to a narrowed focus on a single part of the information portfolio. Therefore, we define the BV of a single piece of information within the information portfolio ($V(I_{\text{Portfolio}})$) as the difference between the BDA's BV, with and without the focal information.

$$V(I_{\text{Portfolio}}) = \frac{1}{m} \cdot E[PV(I)] - \frac{\alpha}{2} \cdot \frac{1}{m^2} \cdot VAR[PV(I)] - \frac{\alpha}{2} \cdot \frac{1}{m^2} \cdot STD[PV(I)] \cdot \sum_{j=1 \setminus I}^m \rho_{I,j} \cdot STD[PV(j)] \quad (8)$$

A single piece of information's BV depends on three key factors: its expected PV as a measure of profitability, its PV's variance as a measure for standalone risk, and the average covariance as a measure for the portfolio effect. Accordingly, an information has a high BV when a) the expected BV is relatively high, b) the BV realizes with relative stability over information periods, and c) the information balances the portfolio toward continuous informativeness.

Regarding the narrow level of data patterns, the portfolio's consideration facilitates interesting analyses of *volume*, *veracity*, and *velocity*, as each characteristic is represented by a model variable. Moreover, organizations can evaluate the completion of their data portfolio using unstructured data sources. Unstructured data delivers valuable insights less frequently than structured data, as the former is not explicitly designed to inform on a specific development within the corporate ecosystem. Similarly, unstructured data delivers insights when structured data does not, as they represent different, non-predefined events. Thus, unstructured data exhibits a portfolio-balancing effect. This effect and the higher standalone risk can be compared within Equation (8), providing a primary opportunity to quantify the data structure's value.

Adjustment for Strategic Prioritization

Second, we can customize our model for the strategic prioritization of the *four Vs*, and again reduce complexity, by exploiting a switch in perspectives. While our basic model covers every nuance of BD, strategic prioritization allows for a concentration on basic characteristics. Thus, we made some adjustments to foster interpretability, and to better

address the first design objective of practicability (O.1). As a first simplification step, we differentiate between characteristics that refer to BDA as a system or a technology, and characteristics that relate to the processed data space. Whereas processing time t_I , the number of information periods n , the value threshold ($K_I = \delta_I \cdot V(I)$), and data quality q_I belong to technology, value time t_I^{MAX} , occurrence probability p_I , generated cash inflows CF_I , and correlations $\rho_{I,J}$ belong to the data space. Propagating this differentiation to the parametrization of our model, technology variables require only a single operationalization, and data variables still require individual operationalization. As a second simplification step, we subsequently can assume an *average* perspective on the data variables ($\bar{p}, \bar{t}^{\text{MAX}}, \bar{CF}, \bar{\rho}$). Thus, we propose the average expected BDA value $E[\emptyset BDA]$ and its variance $VAR[\emptyset BDA]$ as a simplified evaluation. Although this approach is subject to rounding errors, the results promise to be sufficiently robust to enable valid strategic decisions. We come back to this point in our real-world example (Section 5.2.3). Equation (9) illustrates the consolidated outcome of both simplification steps:

$$\begin{aligned}
 V(\emptyset BDA) &= E[\emptyset BDA] - \frac{\alpha}{2} \cdot \frac{1}{m} \cdot VAR[\emptyset BDA] - \frac{\alpha}{2} \cdot \left(1 - \frac{1}{m}\right) \cdot VAR[\emptyset BDA] \\
 E[\emptyset BDA] &= \frac{1}{m} \cdot \Delta_\mu \cdot n \cdot \bar{p} \cdot q \cdot \bar{CF} \cdot \exp\left(\frac{\ln(\delta) t}{t^{\text{MAX}}}\right) \\
 VAR[\emptyset BDA] &= \Delta_{\sigma^2} \cdot n \cdot \bar{p} \cdot q \cdot (1 - \bar{p} \cdot q) \cdot \bar{CF}^2 \cdot \exp\left(\frac{2 \cdot \ln(\delta) t}{t^{\text{MAX}}}\right)
 \end{aligned} \tag{9}$$

On a strategic level, the BV relies on similar key factors, compared to a single information, but on a different level of interpretation. The overall BV is determined by its expected BV as a measure of profitability, its variance as a measure for the standalone risks, and the average covariance as a measure for portfolio risk. Strategically, BDA is then valuable if a) the expected BV is relatively high, b) this BV realizes relative stable, and c) the portfolio provides continuous informativeness. The different levels of interpretation result in decisive distinctions as to single information: While the balancing effect on the portfolio and the standalone BV's stability are equally important for single information, standalone stability is less important on a strategic level. If the number of data sources m converges to infinity, stand-alone risk becomes irrelevant. This is because the variances of portfolio components – the so-called idiosyncratic risks – are less influential than their correlations, or the systematic risks (see *disappearing proof of idiosyncratic variance* [66]).

As an applications field, strategic BV enables the isolated evaluation of the *four Vs*, and even facilitates the definition of a roadmap towards a mature BDA state by ranking them relative to their contributions to overall BV. Matt et al. [68] underscore the practical relevance of this ability, as they identify a clear digitalization or BDA roadmap as a primary success factor in digital transformation. Our model can assist in establishing this success factor, and in overcoming complexity issues originating from the variety of investment opportunities within the BDA universe. The mathematical analysis of model sensitivities, in the forms of partial derivatives or simulations regarding each model variable, may provide the required prioritizations among BDA dimensions. The dimension with the highest partial derivative or the highest simulation value should be the primary strategic objective, the dimension with the second-highest should have second priority, and so on. We conclude that, in summary, our model's strategic representation provides a reasonable, interpretable basis for quantitatively determining a BDA strategy, and thereby, constitutes a first step to fill this research gap. However, our model cannot replace an in-depth analysis of opportunities as a mandatory, second step.

Overall, our model and its two customizations fulfill all design objectives. We therefore conclude that the design specification is valid from the *ex-ante* artificial perspective of EVAL2. Correspondingly, our model fills the addressed research gap.

III.1.5.2 The Insurance Telematics Case, based on Real-World Data

We analyze our model's usability in a naturalistic setting, and evaluate whether the required data can be gathered, by applying a prototypical implementation to the real-world insurance telematics case. Following this, we first describe a central decision problem in insurance telematics, regarding underlying sensing technologies, and provide the necessary background information (Section 5.2.1). Subsequently, we illustrate the data gathering process, in which we first conduct a literature survey on current research on sensing technologies in insurance telematics, and then validate our findings by interviewing a leading executive officer (i.e., the HBD) from a large German insurance organization (Section 5.2.2). We interpret our results and report on further validations with the HBD (Section 5.2.3). Ultimately, we determine the model's usefulness by testing it against acknowledged DSR evaluation criteria (Section 5.3).

The Decision Problem in Insurance Telematics

Digital disruption and BDA enable new business models and tariff concepts within the insurance industry. An impressive example is “usage-based insurance” (UBI). Most prominent in the motor-line, UBI is a tariff concept in which insurance premiums reflect the driver’s actual risky behavior [41]. Sensors capture the driving behavior of insured persons (or cars) and grant discounts depending on the safety and reliability of metered driving styles. Therefore, such *figures of merit* (e.g., acceleration or braking) are combined in scoring functions to determine insurance discounts at the end of a year (for an overview, see [41]).

The insurance industry’s motivation to commit to telematics is manifold: First, the observation of the actual driving behavior improves the accuracies of both risk assessments and premium pricing [45]. Second, telematics may improve the customer risk portfolio. As good drivers have an incentive to enter telematics tariffs, and as bad drivers analogously have incentives to abandon such contracts, telematics technology evokes a positive selection within the customer portfolio [59]. Moreover, monitoring catalyzes changes in driving styles towards more cautious behaviors and reinforces positive selection [32]. Third, insurance organizations hope to decrease their claims costs [cf. 8, 21, 31].

Given these promising prospects, it is unsurprising that an increasing number of insurance organizations enter the telematics market. However, the decision regarding market entry is always accompanied by the choice of sensing technology, which can include either *Onboard Diagnostic* (OBD) dongles, or a smartphone-based variant of *Global Satellite Navigation Systems* (GNSSs) [41]. The OBD dongle is a more traditional telematics device, as professionally installed devices (or “black box” devices) and self-fitting devices that are plugged into OBD interfaces [45]. These devices then transmit data recorded by the cars’ IS to central servers, where they are extrapolated to model driving behavior. The results are retransferred to the drivers’ online dashboards or smartphones, and to the insurance organizations’ billing systems. Smartphones are the considerable alternative, and have matured in recent years. The rapid improvement of measurement capabilities (for an overview, see [56]) now enables smartphones to almost continuously locate the device via its navigation systems (GNSS). This location data can be processed to provide the desired figures of merit. As the recorded location data typically faces problems in terms of data quality and outliers, an enhanced variant of GNSS also exists, which is additionally connected to the car and supported by low-level digital data processing [41]. Other than the

technological differences, the three alternatives (including enhanced GNSS) also differ in terms of business models and risk assessment [41], marking this decision as a typical techno-economic challenge. In observing the current developments in the German insurance market, the two largest automotive insurance organizations both decided to offer telematics tariffs. While the largest organization chose enhanced GNSS, the second-largest competitor committed to OBD. This disagreement underscores the decision's complexity and relevance, and makes this case ideal to validate our theoretical results.

Data Gathering

We follow a two-sided strategy to operationalize our model: We conduct a literature survey regarding existing research results for the three technologies, and challenge these results in an interview with the HBD.

The most differentiating BD dimension in the technological trade-off between OBD and GNSS is *veracity*. Skog et al. [85] test the data qualities of these options for braking events during a drive of 1 hour and 15 minutes, and report on the coverage-scaled data integrity (i.e., 100% minus error rate): 100% for OBD, 99.4% for enhanced GNSS, and 62.8% for GNSS. Similarly, Händel et al. [41] measure the three technologies' coverage and report 100% for OBD, averages of 77.5% for enhanced GNSS, and 88.1% for GNSS based on observations from seven smartphones. We merge both empirical studies, and can calculate data qualities for the three technologies as defined in our model. In terms of BV, information may only create cash flows if it is correctly observed or transferred to the problem at hand, and if telematics devices indicate coverage and integrity. Thus, we can derive data qualities q_I by multiplying coverages and integrities: 100% for OBD, 76.5% for enhanced GNSS, and 55.4% for GNSS. Hence, we conclude a technological advantage for OBD.

We substantiate the *volume* of braking events by again referring to a survey by Skog et al. [85], who record six braking events (deceleration of less than $-2m/s^2$) in their 75-minute drive. We standardize this to a 1-minute information period and can derive the probability of information occurrence equal to $p_I = 5.21\%$. In enriching this result with observations from Eurostat (the European Union's statistical service provider), which states that a German driver spends an average of 43 minutes (or information periods) per day driving, we can determine a total number of information periods per year and per driver ($n = 365 \times 43 = 15,695$).

Regarding *velocity*, both technological alternatives can operate in real-time [41]. Translated to the logic of our model, OBD and GNSS process information with the highest possible information time. In other words, neither suffer from value discounts due to information latencies. The time factor transferred to our model's analytical realm equals 1, and can be neglected in further considerations ($t_I = t_I^{\text{MAX}} = 0$).

Regarding *variety*, as the final BDA dimension, we analyze braking events as additional information in a motor insurance risk assessment. We readdress previous reasoning, in which we interpret variety as interactions within the information portfolio, and negatively correlated information provides evidence when the remaining portfolio does not; positively correlated information primarily confirms the remaining portfolio; and uncorrelated information does both in 50% of occurrences, respectively. Thus, the less correlated the telematics information (e.g., the number of braking events) is to existing non-telematics risk factors (e.g., age, residence), the higher is its actuarial relevance, as the additional data enables further conclusions. While negatively correlated telematics information is improbable, as it would always deliver insights when traditional information fails, uncorrelated, moderately positive, and extremely positive correlated information exhibits high, medium, and low actuarial relevance, respectively. Händel et al. [41] ascribe a high actuarial relevance to our focal braking event information. Therefore, we mirror our preceding reasoning and assume a correlation between braking events and traditional risk factors as equal to zero ($\rho_{I,J} = 0$).

Regarding general planning variables, we suppose a usual parameterization of a long-term planning horizon. Consequently, a risk-free interest rate of 1% leads to discount factors $\Delta_\mu = 100$ and $\Delta_{\sigma^2} = 47.9$. As risk aversion differs in every organization, a behavioral finance approach [81] can be used to assess the value of decision-makers' risk aversion. In this case, we use a risk aversion of $\alpha = 0.002$ [6].

At this point, we have operationalized all variables except for information cash flows CF_I (for telematics: reduced claim costs) and number of information sources m (for telematics: number of customers). As insurance telematics is currently in its early development, and market penetration and profitability are unknown, we explicitly address these economic uncertainties in the analysis section (Section 5.2.3).

Business Value of Insurance Telematics

Having determined most of the required information, we can now proceed with instantiating our model. Therefore, we implemented a prototype in MS Excel, as this standard software's functionalities are sufficient to calculate BDA's BV. We can now use the developed decision model to determine the BV of the additional information, or in this case, braking events. We can partially operationalize the benefits of BDA by inserting gathered data:

$$\begin{aligned}
 V(I_{\text{Portfolio}}) &= 81,701 \cdot \frac{CF_I}{m} - 38.563 \cdot \frac{CF_I^2}{m^2} && \text{OBD} \\
 V(I_{\text{Portfolio}}) &= 62,555 \cdot \frac{CF_I}{m} - 29.881 \cdot \frac{CF_I^2}{m^2} && \text{Enhanced GNSS} \\
 V(I_{\text{Portfolio}}) &= 45,301 \cdot \frac{CF_I}{m} - 21.887 \cdot \frac{CF_I^2}{m^2} && \text{GNSS}
 \end{aligned} \tag{10}$$

An observation of the results from the different technologies reveals that profitability per customer $\left(\frac{CF_I}{m}\right)$, which refers to the BDA's business model aspects, crystallizes as the decisive variable. As this variable is difficult to estimate (see Section 5.2.2), we decided in correspondence with the HBD to take a relative rather than absolute perspective, and standardize the OBD dongles' profitability at 100. This relative approach is suitable, as we explicitly emphasize the comparison of benefits.

If we compare all three alternatives at an equal level of profitability, OBD clearly provides the highest BV, and hence, is the superior technology (OBD: 7,791,469.7; enhanced GNSS: 5,956,663.9; GNSS: 4,311,237.2). However, GNSS users obtain direct feedback after finishing their drive, and do not have to wait until the server provides the information recorded by the OBD dongle. This directness most likely increases the feedback's impact on the users' driving behaviors, and thus, evokes an increased improvement in their risky behaviors. Hence, we conclude that the profitability per customer due to reduced claims costs is higher for GNSS, as compared to OBD dongles. As this advantage can only be roughly estimated, we vary it from 0% to 50%. This relative comparison between technologies indicates that the OBD dongles' technological advantage, due to a higher data quality, always dominates GNSS' economic advantage. However, as Figure 5 shows, reductions in claims costs of at least 34% let the enhanced version outperform OBD dongles.

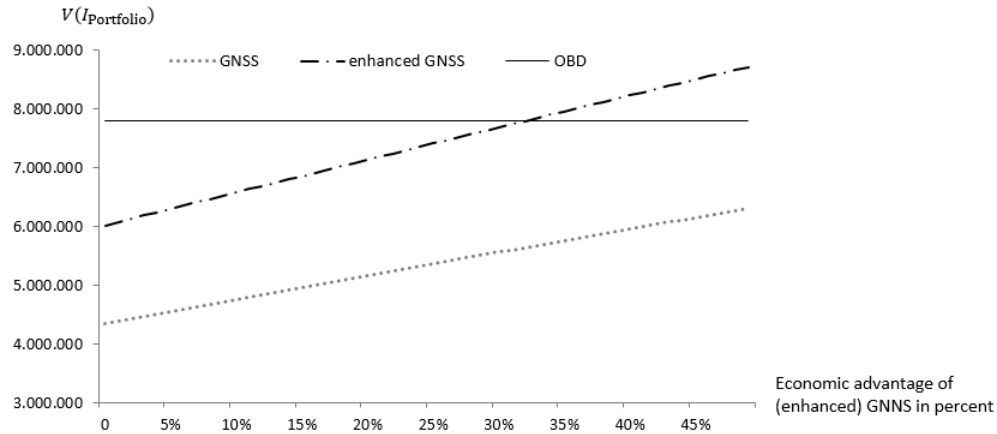


Figure 5. Performance of Enhanced GNSS and GNSS with Increasing Economic Advantage

Additionally, we argue that GNSS’ more intuitive, accessible technology will attract a higher market acceptance. This effect is not visible in the current analysis, as we consider profitability per customer, and not absolute profitability. We account for different market penetrations by multiplying the achieved BV per customer by the number of customers. Again, we standardize the market share of OBD to 100 and vary the advantages of enhanced GNSS from 0 % to 50%. Even if the enhanced GNSS realizes no advantages in terms of claims costs, it still outperforms OBD for a relative advantage in a market penetration of 31% and higher (Figure 6). The adjusted analysis also demonstrates that under the assumption of 10% lower claims costs, enhanced GNSS outperforms OBD when relative market acceptance exceeds 20%.

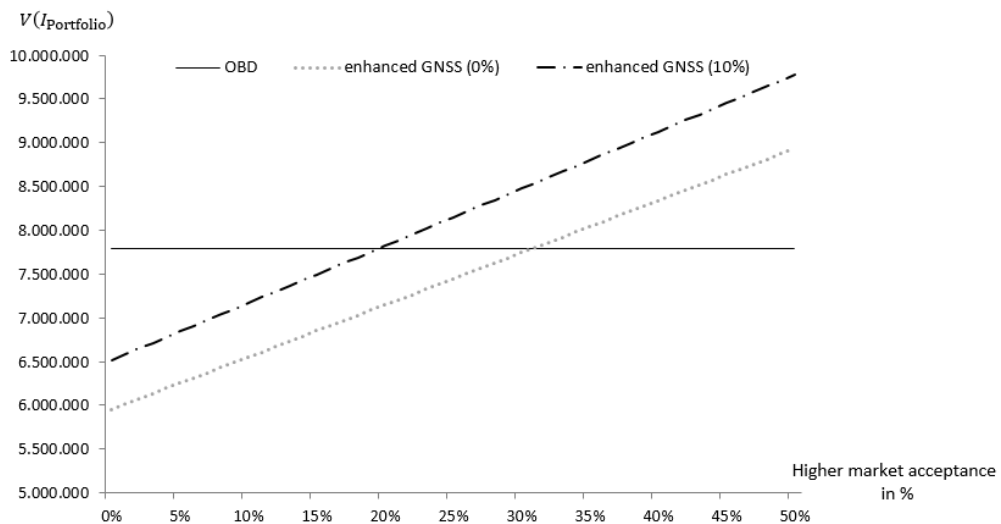


Figure 6. Advantage of Enhanced GNSS (0% and 10% Economic Advantage) due to Higher Market Acceptance

Finally, our analysis reflects the trade-off between the technologies' economic and technological advantages; GNSS is not an option due to its inferior data quality. Enhanced GNSS and OBD differ in the economic advantages of profitability and market penetration, and the technological advantage of higher data quality, respectively. Thereby, we identify enhanced GNSS as the best sensing technology, for low advantages in reduced claims and moderate market advantages. This is a likely outcome for this innovation race because all three effects have approximately the same decision weight in our value model. As a result, enhanced GNSS requires an overall economic advantage of approximately 30% over OBD dongles. Collectively, we agree with the HBD that enhanced GNSS will probably exceed this threshold. Independent of the final outcome, our model condensed the decision problem to estimate whether enhanced GNSS can sufficiently outperform OBD dongles in market penetration and reduced claims costs. Thus, this decision is more concrete than the complex decision regarding sensing technologies, and demonstrates our model's usefulness.

III.1.5.3 Discussion of Results against Evaluation Criteria

We conclude our evaluation efforts by analyzing our results against criteria for assessing the applicability and usefulness of a DSR artifact, as proposed in Sonnenberg and vom Brocke's evaluation framework [88]. Thus, we discuss evaluation criteria assigned to our artifact types; with *model* for our analytical model and *instantiation* for the Excel prototype. This discussion is primarily rooted in the experience we gained through the presented real-world case. Moreover, we conducted an additional interview with the HBD for further validation.

In evaluating *applicability*, the insurance telematics case demonstrates our model's usefulness in real-world BDA decisions. However, the model's operationalization requires many input parameters to operationalize the BDA dimensions of *volume*, *velocity*, *variety*, and *veracity*. These are indispensable to derive a rigorous model for decision support, instead of subjective vagueness or qualitative assessments. Nevertheless, whereas organizations are still inexperienced with data gathering or still miss data relevant to the first decisions regarding BDA initiatives, the HBD confirmed that this effect decreases with the increasing database for the following decisions. As for the case at hand, required data could be gathered from existing literature and our interviewee, except for the business model effects. Therefore, the prototype implements a range of values instead of a single parametrization, allowing for robustness analyses to address potential estimation inaccuracies.

We further tailored our model to the two most important application domains to relieve the burden of excessive data gathering: *in-depth analysis of a single information* and *strategic prioritization of the four Vs*. These adjustments facilitate applicability, as they require less data input. Although the average parameter values of the second adjustment (strategic prioritization) neglect an exact estimation of BDA's BV in favor of increased communicability and interpretability, it is a suitable decision support at the strategic level. On the one hand, strategic prioritization can clearly identify a dominating alternative with the highest, most robust BV. On the other hand, it can establish the lowest possible BDA BV as a more cautious decision criterion by a worst-case parametrization.

Another issue that impacts applicability, besides the high number of parameters, is the complexity of the mathematical expression that requires a prototype for computing the BV of BDA. Its implementation in MS Excel facilitates its use in daily business operations.

Regarding the *impact on the artifact environment and users*, our model strongly influences how practitioners generally approach BDA benefits, and particularly confirms the technology decisions of the insurance telematics industry. It is most noteworthy that our model comprehensibly links the tangible benefits from actions triggered by BDA with the intangible BD's *four Vs*. The HBD further emphasized the usefulness of illustrating technological and economic factors' integrated effects, simplifying a complex technology issue. He stated that "the value model considerably enhances BDA capabilities by breaking down BDA complexity to an understandable extent."

Concerning the *fidelity with the real-world phenomenon* criterion, we argue that our model covers key technological (the *four Vs*) and economic dimensions. Moreover, the model can reasonably process naturalistic parameter constellations. Although the single case still hinders our presumption as to how our model would operate in different technological and economic situations, the HBD has already confirmed the model's fidelity. A central discussion point is, rather, the issue of hidden knowledge and anticipation. Organizations often perceive BDA as a method to discover hidden knowledge and generate unanticipated cash flows. However, our central idea of translating BDA into triggers of actions requires anticipating such *data-action-value relationships*. Thus, despite the business potential of such uncertain unanticipated effects, we take the perspective that relying on BDA effects, which may be intangible but are at least definable, is the superior strategy for sound decision-making.

In evaluating *consistency*, we note that the deductive design, modular integration of components, and the formulation of a closed, mathematical equation avoid side effects and ensure internal consistency. Regarding the latter, the model builds on accepted, justificatory knowledge from related research disciplines (e.g., IS or VBM) to derive design objectives.

In considering our model's *effectiveness and efficiency*, the prototype appeared as an effective tool without performance issues. As it only operates on an unrestricted, closed objective function, no computational issues will occur in any application settings.

III.1.6 Conclusion

Even though academia and practice agree on big data analytics' (BDA's) substantial, disruptive impact on traditional business models throughout the economy, in reality, strong guidance is still required in practice as to how to evaluate BDA's business value (BV) and make decisions regarding BDA initiatives. To respond to this need, support organizations, and bridge the research gap, we developed an analytical model that integrates the technological characteristics (i.e., the BD's *four Vs: variety, velocity, veracity and volume*) with the economic impact of information based on established scientific approaches to illustrate the process of value creation, and to determine BDA's BV.

We commit to the *information use* perspective as our guiding principle. Accordingly, we argue that information and BDA do not create BV, per se, but trigger actions and decisions that do generate tangible benefits. Therefore, we integrate the *value* of information use as fifth BDA dimension, whereas more profitable triggered actions create higher BV. In a second step, we adjust these economic benefits for the technological constraints of the *four Vs*. As for *volume, veracity, and velocity*, BDA's BV increases with the frequency of information occurrences, the fraction of potential information observations, and the information processing speed. As for *variety*, more balanced processed information portfolios ensure the consistency of BDA's BV. Finally, we quantitatively and objectively assess BDA's BV based on VBM.

Overall, our model provides a theory-based understanding of BDA value creation, while also guiding managers regarding a variety of BDA investment decisions. It contributes to the prescriptive body of knowledge related to the economic stream of information systems research and diminishes the research gap that results from the techno-economic development. It is the first approach to integrate BDA's four technological dimensions while incorporating *value* as fifth dimension. The model's design specifications are guided by

theory-backed design objectives and meet the requirements from practice as confirmed by a subject matter expert. The model and the software prototype further fulfill established DSR evaluation criteria.

The model can be applied to different domains due to its high flexibility. The real-world insurance telematics scenario confirms its applicability and usefulness, despite the burden of excessive data gathering derived from literature and expert estimations. Nevertheless, the model could be applied to a much larger variety of technological and economic situations to get more substantial experience in data collection and context-specific adjustments. Further, we assume that we do know the *value* of information use. In reality, the determination of a value of a single information use may be not as easy, but can be estimated by experts. Estimations may be getting easier and more accurate over the course of time and with growing experience. As answer to this, the model could also address a data cluster analysis or the inclusion of additional data sources by integrating further model parameters to support the evaluation of the fifth dimension *value* as preliminary step to the evaluation of BDA's BV. Therefore, we encourage our colleagues to help us address the range of applicability within future research.

III.1.7 References

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IV Normative Guidance on Strategic Redesign Decisions

IV.1 Customer Experience Versus Process Efficiency: Towards an Analytical Framework About Ambidextrous BPM¹

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Abstract

Digitalization forces organizations to rethink classic operating models and develop completely new ways about how to run business. This revolution also spills over to the management and design of business processes. New market transparency and the increasing interconnectedness of customers define customer satisfaction and operational efficiency as two equal strategic objectives. Ambidextrous business process management (BPM) demands the symbiosis of exploitative BPM to ensure organizational efficiency and explorative BPM to create process designs that truly excite customers. A key challenge is to properly balance the different capabilities. Therefore, we propose an analytical framework providing an in-depth understanding about effects and interdependencies of this challenge. As justificatory knowledge, we drew from literature on value-based BPM and customer confirmation/disconfirmation paradigm to unite the different perspectives. Based on our framework, we match process and customer types to generic design principles and provide concrete guidance on the establishment of ambidextrous BPM.

¹ Improved version

IV.1.1 Introduction

Digitalization imposes new challenges to modern business process management (BPM) and customer relationship management (CRM) (Bharadwaj et al. 2013). While the high relevance of customer satisfaction for an organization's profitability is widely accepted (Anderson and Mittal 2000; Gruca and Rego 2005; Heskett et al. 1994), its importance is even increasing with customers becoming ever more interconnected. An impressive example of technology-enabled interconnection is online social networks. About 65 percent of American adults were using at least one social networking site in 2015 compared to only 7 percent in 2005 (Aperrin 2015). This increasing interconnectedness leads to a mutual suggestibility among customers, the so called word-of-mouth-effect (Relling et al. 2016). Positive and negative experiences of customers may cascade through the entire customer base of an organization making customer satisfaction a topic of utmost relevance. In addition, increased market transparency exposes organizations to a more intense competitive pressure on the offered price and therefore also on process efficiencies (Soh et al. 2006). Both developments together confront organizations with a dilemma: Whereas interconnectedness requires organizations to please customers at any costs, transparency demands them to improve process efficiency. We define this issue as the "experience-efficiency trade-off" (E-E trade-off) of process design. In order to survive in this contradictory environment, organizations need an integrated customer-process-strategy and have to design their process portfolio according to these challenges.

Against the background of the described digital challenges, strategic alignment as one success factor of BPM is crucial and new research questions enter the agenda of the BPM discipline (Rosemann and vom Brocke 2015). In this context, Michael Rosemann (2014) emphasizes the need for *ambidextrous BPM* to solve the E-E trade-off. Rosemann (2014) argues that organizations have to stimulate exploitative as well as explorative strengths at the same time. Thereby, exploitation demands cost- and time- efficient fulfillments of basic customer needs (Rosemann 2014). Exploration aims at the development of new and digital "process designs that truly excite customers" (Kohlborn et al. 2014, p. 636). In order to establish the right balance between both paradigms within their process landscape, organizations need to determine the strategic design orientation (customer-centric versus efficient) for every process separately. Even increasing complexity, they additionally have to decide between risk-averse designs following the principle of "better safe than sorry" and risk-taking designs pursuing the idea of "nothing ventured is nothing gained" (Alexandrov 2015, p. 3001). Processes can either be designed "safe" with only few variation in their

outputs, often associated with high costs for quality control or they can be designed risk-taking accepting a wider range of output quality. We define this design question as the “risk trade-off” of process design. Summing up, organizations are continuously facing the question, how to (re-)design their processes. Therefore four archetype strategies exist: 1) *risk-taking and efficient*, 2) *risk-taking and customer-centric*, 3) *risk-averse and efficient* and 4) *risk-averse and customer-centric*. An ambidextrous process design strategy, defined as the planned coexistence of the 4 archetype strategies reflecting the needs of the organizations business model, as a solution to this dimensional plurality, requires the ex-ante definition of strategic targets for every process. To the best of our knowledge the current state of literature does express the need for ambidextrous BPM, but it does not address the separate prioritization of design targets with respect to ambidextrous BPM. Supported by the high relevance of the topic given the impact of digitalization, we formulate the following research question:

How do risk- and E-E trade-off affect strategic orientation in business process design?

When approaching this research question, one key challenge emerges: Solving the two design trade-offs requires a deep understanding of their mechanics and interdependencies. Therefore it is essential to combine two related, but still different research disciplines: Knowledge from CRM about the effects of customer satisfaction and process design competencies from BPM need to be harmonized. Following this integrative approach, we use analytical modelling and mathematical-deductive analyses as our research method. Thereby, we set up an analytical framework using established CRM and BPM components. By means of this framework, we analyze the interplay of different process and customer types. Finally, we match such process profiles to exploitative and explorative design principles to answer our research question.

Our analyses propose a differentiation into basic-, performance- and excitement processes. Thereby risk-taking designs are beneficial for excitement processes whereas risk-averse designs are favorable for basic and performance processes. For the E-E trade-off, we conclude customer-centric designs for excitement processes if a corresponding redesign can exploit their upside potential and really excite customers. For basic processes, we propose customer-centric designs until an acceptable performance is promised to control for extreme disappointments. Finally, performance processes do not have a “one fits it all” solution and require case-specific analyses. Thus, our article contributes to literature in two ways. First, we provide insights into the interplay of the E-E trade-off and the risk trade-off and point

out the importance of an ambidextrous strategy in process design. Second, we derive recommendations for design decisions within the four archetype strategies, providing organizations with concrete strategic guidance on how to design their processes.

The remainder of this paper is structured as follows. After the brief motivation of our research question, we provide the theoretical background on the relevant BPM and CRM theories in Section 2. On this foundation, we elaborate our framework in Section 3. Section 4 theoretically analyzes and discusses the E-E trade-off and the risk trade-off within the environment of the framework. Finally, we summarize our results, point out limitations and provide opportunities for future research in the concluding Section 5.

IV.1.2 Theoretical Background

IV.1.2.1 Ambidextrous BPM

The BPM Lifecycle as probably the most popular management concept of the research discipline can be classified into six phases: identification, discovery, analysis, redesign, implementation and monitoring (Dumas et al. 2013). While every phase has a significant contribution to the success of BPM, the prevalent opinion in literature assigns process redesign the highest value (Zellner 2011). Thereby, the interpretation of the term process design varies with respect to the level of abstraction. It ranges from very high-level interpretations as definitions of how work is performed (Dumas et al. 2013) to very detailed interpretations as process models. According to the strategic scope of this paper, we follow a high-level interpretation of process design. Not surprisingly given the high relevance of this management task, the BPM community developed several different methods to support business process redesign (Harmon and Wolf 2014; van der Aalst 2013; Vanwersch et al. 2015). Despite the diversity of the redesign tool kit, almost every approach begins with setting strategic process objectives (Limam Mansar et al. 2009). Therefore, our framework for strategic process orientation does not add a new mosaic piece to the redesign-literature, but it rather enhances existing approaches to a more holistic concept.

To realize the presumably high value from process design, the set of strategic process objectives have to be in line with the corporate strategy (vom Brocke et al. 2014). When classifying generic corporate strategies, Porter (1980) differentiates between cost leadership and differentiation. In a succeeding paper, Porter and Millar (1985) substantiate these generic strategies for the process level. Cost leadership is the process strategy to sustainably produce on – compared to competitors – lower cost levels, mostly realized by technological advantages in production or by learning effects. In contrast, the differentiation strategy aims

at producing superior product quality or product variety. In the past, organizations could choose between these two archetypes or decide for a niche strategy between the both extremes. Today, organizations need to execute them in parallel and follow ambidextrous strategies. Due to lower switching costs, customer loyalty is hard to achieve (Valvi and Fragkos 2012). Thus, differentiation appears as a promising answer. Moreover, the current trend of digitalization enables customers to be highly interconnected leading to higher market transparency and ultimately to higher competitive pressure. Cost leadership appears beneficial against this development. Strategic singularity is therefore not possible to survive today's extreme situation and ambidexterity becomes mandatory.

Although, ambidexterity is not new to IS literature (Markides 2013; Mithas and Rust 2016; Raisch and Birkinshaw 2008), there is only little attention on ambidexterity in BPM. However, the emergence of the E-E trade-off between customer-centric designs (explorative BPM) and efficient designs (exploitative BPM) exactly requires such an ambidextrous thinking. According to the paradigm of strategic alignment, ambidexterity can only be established on the corporate level when the process designs reflect such a proper mix. Looking at the current focus of BPM research with respect to strategic orientation, most redesign approaches put process performance as their objectives. Thereby, process performance is often considered as a multi-dimensional construct (Limam Mansar and Reijers 2005). As a very popular example, the framework of the devil's quadrangle groups different performance measures into the dimensions time, cost, quality and flexibility and thus, enables a clear analysis of different process redesign alternatives (Limam Mansar and Reijers 2007). The name of the framework reflects the issue that improving process performance in one dimension is always accompanied with impairing in at least one of the other dimensions. The considered dimensions have a strong focus on process-internal dimensions and customers are only addressed indirectly. Whereas process time and costs can be classified as efficiency objectives, process flexibility and quality are at least partly customer-centric. Process flexibility is the ability of a process to cope with contextual changes by adapting its structure and behavior in a goal-oriented manner (Wagner et al. 2011). From an operational perspective, process flexibility splits into functional and volume flexibility (Afflerbach et al. 2014). While volume flexibility enables increasing or decreasing the amount of the process output above or below installed capacity (Goyal and Netessine 2011) and thus follows an efficiency-related interpretation, functional flexibility enables delivering the output variety demanded by the organization's customers (Anupindi et al. 2012) and relates to customer-centric objectives (Hall and Johnson 2009; Hammer and

Stanton 1999). Also process quality can be interpreted as internal process quality and consider error rates or it can follow an external interpretation in terms of quality perceived by customers. As process error rates are more intuitive for operationalization, the internal interpretation is rather dominating. Rosemann (2014) underscores the outlined underrepresentation of explorative components in BPM. Thereby, he criticizes that opportunities of explorative strategies are often neglected and future revenues from innovative, IT-enabled processes are outside the design focus. Due to digitalization, explorative strategies are gaining importance and redesigning processes needs a strategic rethinking towards the coexistence of customer-centric and efficient process designs. In terms of the risk trade-off between safe and unstable process designs, BPM mainly commits to a risk-averse orientation. This commitment is supported by famous concepts like six-sigma (Conger 2010) or value-based BPM (Bolsinger et al. 2011). However, Alexandrov (2015) shows that it is rational for organizations to balance their strategies with risk-taking and risk-averse components. Thus, a strategic rethinking is again required.

IV.1.2.2 Value-based Management as Integration Frame

With this paper we want to take up Rosemann's (2014) thoughts and develop a quantitative model on how to position within the tension field between exploitative and explorative design. The main challenge of this research objective is to integrate the different but related approaches from CRM and BPM on a common basis. To overcome this challenge, we start with value-based BPM as an accepted research stream in BPM on process design. This stream typically aims at optimizing process cash flows in redesigning processes (Bolsinger 2015). As extension, we ascribe revenues as an essential component of process cash flows to an organization's customers who generate revenues and integrate insights from the Kano model (Kano et al. 1984). Depending on how the process output fulfills the needs of the customers, overall customer satisfaction and simultaneously customer profitability or revenues accordingly increase or decrease (Kano et al. 1984). Especially relevant for this basic idea, is Kano et al.'s (1984) differentiation between three types of customers with respect to the underlying relationships between customer satisfaction and the fulfillment of expectations. For our purpose of connecting Kano et al. (1984) over their results on customer perceptions and process revenues from value-based BPM, we transfer this differentiation concept of customers to processes with respect to their outputs. Thus, so called basic processes should perform with low deviation in their output to avoid dissatisfaction of the customers. Dissatisfaction would lead to a lower retention of the customers and therefore to reduced revenues (Anderson and Mittal 2000; Heskett et al.

1997). Excitement processes may differ in their output variety as they can only positively affect customer satisfaction and therefore have a high contribution to corporate revenues. This early discussion already shows that customer-centric analyses have also implication on the proper riskiness of the ideal process design. Consequentially, the risk trade-off is not orthogonal to the E-E trade-off but both decisions mutually influence each other. This interdependencies are a key challenge demanding the integration of customer and process perspectives in order to find the right ambidexterity.

Such an integration of CRM and BPM as theoretical underpinnings needs to take place on the conceptual and on the methodological level to achieve a sound framework. On the conceptual level, the process output is the linking element. On the customer side, customer satisfaction and therefore profitability critically depends on the fulfillment of customers' expectations towards the process output. On the process side, the process output is the final result of the underlying business process and therefore also determines its operational efficiency. As a result, the process output does not only integrate the customer and the process perspective, but it also unites the economic opponents of profitability and efficiency.

In order to bring this conceptual integration down to the methodological level, we draw upon the results of value-based management (VBM) because of three reasons: First, VBM abstracts as a paradigm of corporate decision-making from domain-specific conditions by taking an economic perspective and by translating problem specifications into the neutral measure of cash flow effects. Taking this neutral perspective enables VBM to take customer, process and integrating perspectives. Whereas customer-centric designs improve the profitability of an organization's customers and thereby also corporate cash inflows, efficient designs decrease process cash outflows sacrificed for the production of the process output. Thus, the residual measure of cash flows constitutes the equivalent to the process output as linking element on the methodological level. Structurally, both designs increase cash flows either by reducing cash outflows (efficient designs) or by increasing cash inflows (customer-centric designs). This structural equivalence makes the effects comparable and integrative. Second, VBM emphasizes risk as the second decisive factor of corporate decision-making. Thus, it is directly applicable for the risk trade-off as well. Third, the benefits and the applicability of the paradigm have already been demonstrated in CRM and BPM (Bolsinger 2015; Buhl et al. 2011; Kumar 2009; Kumar and Pansari 2016). Based on this reasoning, we can conclude the suitability of VBM as our methodological integration frame.

In order to further substantiate the suitability of VBM as integration frame, we now outline its theoretical foundation. Within the last decade, VBM has established as the predominant paradigm for economic research and practice in corporate decisions (Buhl et al. 2011). The success of VBM can be traced back to the incorporation of a long-term perspective of the firm value and the focus on a sustainable increase of the firm value within corporate decisions (Ittner and Larcker 2001; Koller et al. 2015). Basically, VBM represents an extension of the share-holder value approach by (Rappaport 1986) which was elaborated by Copeland et al. (1994) and by Stewart and Stern (1991). The long-term perspective of VBM implicitly results in the completion of the more general stakeholder value approach (Danielson et al. 2008). In order to fully implement VBM in an organization, decisions on all hierarchy levels have to be aligned to a firm value maximizing strategy. Thus, there is a strong need for organizations following the VBM approach to identify and quantify the value contributions – typically measured by the effect on future cash-flows – of every single asset and decision. The basic principle behind this required decomposition is that the firm value can be calculated by aggregating all current and future assets of an organization. For well-founded decisions, additional knowledge about the time value of money, as well as on the risk attitude of a decision-maker is mandatory (Buhl et al. 2011). Besides those parameters, the choice of an appropriate valuation function for determining the value of single assets is crucial. In this choice, the concrete decision situation should be taken into account as investment and decision theory suggest (Buhl et al. 2011; Damodaran 2012). Whereas the net present value (NPV) of future cash flows with a risk-free discount factor is common for decisions under certainty, a more differentiated view is required for a situation with risk. Decisions under risk should be grounded on the NPV method incorporating a risk-free discount factor for risk-neutral decision-makers. In contrast other methods like the certainty equivalent method or the risk-adjusted NPV have to be applied for risk-averse decision-makers (Copeland et al. 2005). The applicability of VBM on our research topic requires the compilation of the responsive behavior of customers and processes on different process design strategies into cash flow effects. This cash flow focus ensures the comparability across effects and compatibility to the valuation functions from VBM.

IV.1.2.3 Customer Effects

Disassembling the E-E trade-off into its singular components, *customer satisfaction* as the experience component plays an important role for the cash inflow perspective. Certainly, customer satisfaction itself is not the objective criterion, but there is evidence that customer satisfaction leads to improved customer retention which ultimately results in increased cash

inflows (Anderson and Mittal 2000; Danaher and Rust 1996; Gruca and Rego 2005; Heskett et al. 1997; Larivière et al. 2016; Parasuraman et al. 1988). Besides, the American Customer Satisfaction Index, supposed by Fornell et al. (1996), the so called Kano model is predominant in customer satisfaction research (Kano et al. 1984; Matzler et al. 1996). Both approaches aim at determining the satisfaction of an organization's customers. The Kano model conceptually manifests the confirmation disconfirmation paradigm (Oliver 1980). According to this paradigm, customer satisfaction evolves from the comparison of a customer's expectations prior to the actually perceived experience about the quality or performance of the product or service (Matzler et al. 2004). If the perceived performance falls short of the customer's expectations, dissatisfaction or under-fulfillment realizes: Correspondingly, customers feel satisfied in the case of over-fulfillment, if the perceived performance exceeds expectations. In case of a balanced relationship between expectations and perceptions, customers will feel moderately satisfied (Matzler et al. 2004). Kano et al. (1984) enhance this theory and further differentiate these findings into three different relationships: Basic, performance and excitement relationships or requirements. The fundamental idea of those different types of requirements can be easily transferred on products or services as they are just the aggregation of different requirements. Thus, products or services that are classified as basic factors – which in turns means that in an aggregated view, basic requirements predominate the product or service – can only negatively influence satisfaction. In the case of under-fulfillment, customers feel extremely dissatisfied and in the case of over-fulfillment they do not feel satisfied. As depicted in Figure 1, basic factors (solid line) show an asymmetric experience-expectation relationship in the shape of a negative exponential function with the fulfillment of expectations on the x-axis and the resulting satisfaction on the y-axis. Figure 1 illustrates the high disappointment potential and the absence of any satisfaction potential for basic factors. The typical example of a basic factor is the cleanliness of a toilet. Excitement factors do not suffer from partly or even total under-fulfillment, but they strongly increase customer satisfaction in case of over-fulfillment of expectations. The corresponding curve (dashed line) is shaped like a positive exponential function illustrating their satisfactory potential and their robustness against under-fulfillment. Performance factors are linearly shaped and translate the fulfillment of expectations directly proportionally into satisfaction or dissatisfaction. Figure 1 depicts the positive influence of over-fulfillment on customer satisfaction and the negative influence on satisfaction in case of bad performance (dotted line).

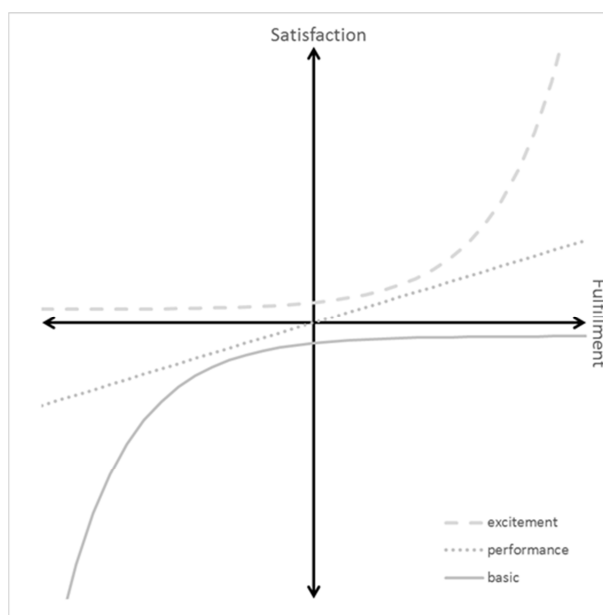


Figure 1: Kano model

With customer satisfaction directly influencing future cash flows of an organization (Anderson and Mittal 2000; Danaher and Rust 1996; Gruca and Rego 2005; Heskett et al. 1997; Larivière et al. 2016), the role of pleasing customers as a prerequisite for long-term economic success becomes evident. Connecting Kano’s (1984) insights about satisfaction-relationships and the outlined relationship between customer satisfaction and future cash flows shows that the cash inflows generated by a process, strongly depend on the classification of the process’ outputs as basic, performance or excitement outputs. As Kano’s (1984) model points out, processes can exacerbate different dynamics on customer satisfaction. Thus, different risk- and E-E strategies conditioned on the classification of produced output may be beneficial. With respect to our research question “*How do risk- and E-E trade-off affect strategic orientation in business process design?*” we hypothesize, that the exponential relationships for excitement and basic factors may make process fulfillment — defined as the degree to which the customers’ expectations are met in their experience — more important as compared to performance processes and their linear dynamics. In addition, the asymmetric risk profiles of excitement processes and basic factors may suggest different risk strategies. We investigate these first hypotheses in the course of this manuscript.

IV.1.2.4 Value-based Process Management

As already outlined, process costs or cash outflows are the predominant decision criterion in BPM. In the mid-nineties, BPM scholars began to criticize this one-sided view (Kanevsky and Housel 1995) and applied the principles of VBM on process decision-making (Bolsinger

et al. 2011). Following this paradigm, Gullledge et al. (1997) postulated the equal importance of cash inflow components. Within the last years, this mindset gained ever more importance in the community and the research stream of value-based BPM emerged (vom Brocke and Sonnenberg 2015). The basic idea of value-based BPM is to interpret an organization as a network or portfolio of processes which contribute all together to the firm value of the organization (Bolsinger et al. 2011). In this interpretation, improving processes gets a strong focus on the long-term maximization of the firm value, as the process value is correspondingly defined as its contribution to the corporate value (Buhl et al. 2011). Next to value-based BPM as the “cleanest” application of VBM on process decision-making, some closely related approaches like value-focused BPM (Neiger and Churilov 2004; Rotaru et al. 2011), value-oriented BPM (vom Brocke et al. 2010) and value-driven BPM (Franz et al. 2011) exist as well.

Process redesign developed as a problem domain of special interest for the approach of value-based BPM (Bolsinger et al. 2015). Whereas some works focus on the control flow in order to figure out the best design alternatives (Bolsinger 2015; vom Brocke et al. 2010), others concentrate on process performance and process structures (Afflerbach et al. 2014; Linhart et al. 2015). Although, these approaches put process cash inflows into the focus of design questions, the effects of process redesign on this decisive factor are often modeled exogenously. The response of a process’ profitability to a redesign initiative is thereby primarily determined by the process behavior. Customer reactions are only considered implicitly. However, exactly the synthesis of CRM and BPM is relevant for strategic decisions about process design as we already motivated in the introductory section.

Summing up, the current state in BPM literature in general and in value-based BPM in particular, mainly focuses on performance tuning and cost-risk optimization (Reijers and Limam Mansar 2005). Recently, BPM begins to discover the explorative perspective and highlights the need for innovative, risk-taking and customer-centric designs (Rosemann 2014). Currently, the outward perspective on customers is underrepresented in BPM literature (Bolsinger et al. 2011; Bolsinger 2015; Reijers and Limam Mansar 2005). The key contribution of this paper lies exactly in integrating the customer and process side for determining proper design objectives and in deriving a quantitative framework which indicates which of both sides should be emphasized.

IV.1.3 Model

When establishing an ambidextrous design strategy with the E-E trade-off on the one hand and the risk trade-off on the other hand, there arise two key problems: First, organizations have to separately define design principles for each process with respect to their relevant characteristics. Given the large number of processes, this task of strategic alignment suffers from very high complexities. As a response, the development of a strategic framework providing concrete strategic guidance on defining design principles is mandatory to reduce complexity and to foster consistency across the process landscape. Second, the integration of the internal process perspective and the external customer perspective is crucial to holistically investigate the interplay between an organization's business processes and its customers. Accordingly, our units of analysis are so called "value or primary activities", i.e. business processes with a direct interface to customers (Porter and Millar 1985). Please note that the scope of our framework is to provide a better understanding about the strategic effects of process design and the definition of process and customer types, which are relevant for a proper strategic orientation. Our framework should not get confound with a decision model for operative redesign decision as it takes a more high-level, strategic view on business process redesign. Operational redesign decisions require more detailed analyses and should follow our strategic investigations in a second step.

As methodological foundation we draw upon the results of VBM. This famous paradigm is accepted in both, CRM, as concepts like the customer lifetime value illustrate, and BPM, as the concept of value-based BPM demonstrates. A highly acknowledged approach within the tool-kit of VBM is to insert (the NPV of) cash flows into an appropriate valuation function in order to obtain a comparable decision criterion. In our framework, we use the expected value as a typical valuation function from VBM. Although the expected value reflects a risk-neutral decision-maker and thereby contradicts the typical assumption of risk-aversion, this simplification enables us to separate effects from the process and customer sides and effects from the decision-makers' risk attitudes. As a result, we can derive more general and clearer results. In Section 4 we discuss our findings for risk-averse decision-makers and show their robustness against this assumption.

In order to further increase the comprehensibility of our framework, which is crucial for the purpose of our framework, we modify the expected NPV as our objective function in two ways. First, we directly consider cash flows and not their NPV. If the underlying cash flows follow an independent, identical distribution — a very common condition in business

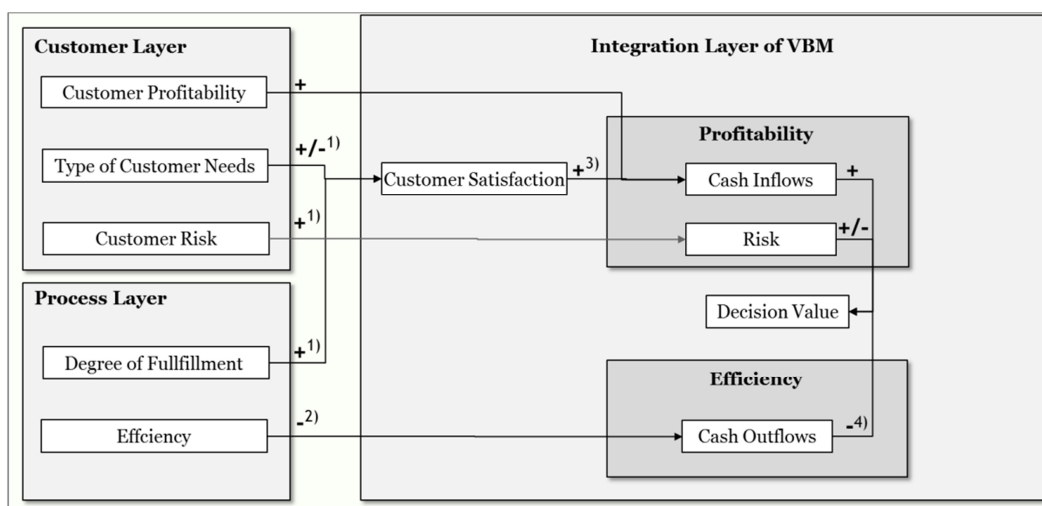
process management (see e.g. Bolsinger et al. 2011; Buhl et al. 2011; Murray and Haubl 2011) — the NPV can get reduced to a constant discount factor. As the pure discounting, does not alter decisions and as the scope of our model lies on the strategic decision and not on an accurate value estimation, we can abstract from this complexity and use the periodic cash flows instead as a proxy. Second, we distinguish between cash inflows CI coming from the external customer side and cash outflows CO coming from the process side. The clear assignment of cash inflows to the customers and cash outflows to processes is an approach which considerably increases the comprehensibility of the interplay between both sides. Moreover, it does not influence our results, as the assignment of cash flows to research objects is problem specific in VBM. Whereas the BPM literature traditionally assigns both, cash in- and outflows to processes (e.g. Bolsinger et al. 2011; vom Brocke et al. 2010), CRM literature assigns all cash flows to the customer as its central research object (e.g. Gupta et al. 2006). For our integrative purpose, basically all combinations in between these extreme assignments would theoretically be possible. Accordingly, we have chosen the clearest variant. Using the sum of cash in- and outflows as objective function, increasing cash inflows (or increasing customer satisfaction) and decreasing cash outflows (increasing process efficiency) finally have the same effect. Our objective function V then equals

$$V = E(CI) - E(CO) \quad (1)$$

Equation (1) separately represents the relevant factors for a proper strategic orientation for the focal business process. The expected cash inflows (first term of equation (1), resulting from selling the process output to the customer, is a measure for customer profitability. The expected cash outflows (second term of equation (1) resulting from executing the underlying process to produce the process output is a measure for process efficiency. In order to properly compile the cash in- and outflow components, we draw back on the results from CRM for the inflow side and from BPM for the outflow side. As justificatory literature for the process layer, we refer to Bolsinger et al. (2011) who transfer the principles of VBM to BPM in the context of process redesign. The basic idea of their model is the description of process cash (out-) flows on the basis of a stochastic distribution. They show that the value of a process can be calculated by inserting the normal distributed cash flows into the chosen valuation function. Thereby, the process value is completely determined by the expected cash flows (efficiency) and their variances within the integration layer of VBM.

Considering the customer layer, Gruca and Rego (2005) illustrate that operational cash inflows i.e. profitability linearly depend on customer satisfaction. Thus, the substantiation of

the cash inflows requires the compilation of customer satisfaction. For this purpose, we refer to the well-established Kano model (Kano et al. 1984) who differentiate between three types of relationships between the realized customer satisfaction and the degree of fulfillment of the customers' needs towards the process output. At this point, we can again bridge the customer and the process world. The degree of fulfillment is a typical process characteristic, which is closely linked to customer satisfaction and thereby to cash inflows. The higher the expected degree of fulfillment, the higher the expected customer satisfaction and the higher expected cash inflows. To model this casual chain, we begin with the degree of fulfillment. Analogously to the reasoning from Bolsinger et al. (2011) about process cash flows, we can describe the degree of fulfillment also by a normal distributed random variable. In a second step, we transfer the threefold manifesto of Kano (1984) to the process level by differentiating between basic, performance and excitement processes and modeling the different satisfaction mechanics. In a third step, we transform the intermediate result for customer satisfaction into cash flows and insert them into our valuation function. Following this procedure, we describe the customer value on the basis of the expected fulfillment as a measure for customer profitability and the fulfillment variance as a measure for customer risk. Finally, we integrate both sides in the valuation layer within our objective function. Figure 2 illustrates the reasoning above and graphically summarizes our results, whereas the arrows show the direction of influence, the plus/minus indicate a positive or negative influence. Below, we substantiate our objective function in more detail.



1) Kano et al. 1984; 2) Limam Mansar et al. 2009; 3) Gruca and Rego 2005; 4) Bolsinger et al. 2011;

Figure 2: Basic Idea of CRM-BPM-Framework

A key result of value-based BPM is, that process cash flows follow a normal distribution (see e.g. Bolsinger et al. 2011; Buhl et al. 2011; Murray and Haubl 2011). This implies that

the expected value and the variance of the process cash flows completely define the value of a business process. The central limit theorem and variations from it provide the justification for this result. As the number of process executions n within a single period is sufficiently large and as the other assumptions of identical and independent repetitiveness hold for business processes, the central limit theorem states that process cash flows are normally distributed (Bolsinger et al. 2011). In our case, the expected process cash outflows sacrificed for the production of the process output in a single period $E(CO)$ calculates by multiplying the number of executions n and the expected outflows μ_{CO} per process instance.

$$-E(CO) = -n \cdot \mu_{CO} \quad (2)$$

For compiling process cash inflows, we begin with modeling the degree of fulfillment as the bridging variable between the customer and the process layer. Therefore, we transfer the reasoning about cash flows as the central process characteristic of value-based BPM to the degree of fulfillment as the central process characteristic of CRM. The identical and independent repetitiveness of processes makes the central limit theorem also applicable for the degree of fulfillment. If a process fulfills the needs of an organization's customer to the expected degree μ_F and variance σ_F^2 , the total fulfillment of the entire customer base i.e. over the total number of process executions n then also follows a normal distribution with mean $n \cdot \mu_F$ and variance $n \cdot \sigma_F^2$. In order to translate the fulfillment into satisfaction, we need to consider the different mechanics toward the three kinds of process outputs and derive an analytical relationship for each output type. Excitement outputs are ideal for an organization as disappointing customers does not decrease customer satisfaction whereas an over-fulfillment of expectations leads to an exponential increase of satisfaction. In terms of risk, the organization only faces "upside risk" meaning that it can only win and not lose in satisfying their customers. Moreover, their winning potential increases exponentially with the degree of fulfillment. Mathematically, an exponential function $\exp(bF)$ mirrors this ideal relationship between satisfaction and fulfillment F where b is a measure for customer sensitivity towards fulfillment. The higher the sensitivity b the more satisfied feel customers in the case of excitement. Basic outputs follow the same logic in the opposite direction. They are the worst-case type for an organization as over-fulfillment is not rewarded or perceived by customers whereas disappointment leads to an exponential decrease of satisfaction. In terms of risk, the organization only faces "downside risk" meaning that it can only lose and not win in satisfying their customers and their losing potential is exponential. A negative exponential function $-\exp(-bF)$ mirrors this undesirable relationship. Again b is a measure for customer sensitivity on fulfillment and the higher b the worse the reaction

on disappointment. Performance outputs stand in between these extremes. Over- and under-fulfillment are equally perceived and both linearly increase and decrease customer satisfaction. The corresponding mathematical function bF shows this ambiguity. In order to finally transfer our intermediate results into cash inflows, we refer to Gruca and Rego (2005) who empirically illustrate a linear relationship between both constructs. The profitability p monetizes satisfaction and is defined as the exchange rate between satisfaction and cash inflows as illustrated by Gruca and Rego (2005). On this foundations, we can compile the cash inflow components of the objective function. Therefore we integrate the respective cash inflow functions over the density of the fulfillment.

$$\begin{aligned}
 & \int p \cdot \exp(b \cdot F) f(F) dF && \text{e-process} \\
 E(CI) = & \int p \cdot b \cdot F f(F) dF && \text{p-process} \\
 & \int -p \cdot \exp(-b \cdot F) f(F) dF && \text{b-process}
 \end{aligned} \tag{3}$$

Two things are important to note when solving these integrals. First, the solution for the exponential functions of excitement and basic processes correspond to the expected value of a log-normal distribution and are therefore known in stochastic theory. Second, the linear relationship from the performance factors follows the same logic as for the cash outflow component. Thus, we already know the solution for performance processes as well. Equation (4) shows the complete substantiation for the customer side.

$$\begin{aligned}
 & p \cdot \exp\left(b \cdot n \cdot \mu_F + \frac{b^2}{2} \cdot n \cdot \sigma_F^2\right) && \text{e-process} \\
 E(CI) = & n \cdot p \cdot b \cdot \mu_F && \text{p-process} \\
 & -p \cdot \exp\left(-b \cdot n \cdot \mu_F + \frac{b^2}{2} \cdot n \cdot \sigma_F^2\right) && \text{b-process}
 \end{aligned} \tag{4}$$

Synchronizing the process side with the customer side into one equation, we finally get to our final objective function V which is illustrated in equation (5).

$$\begin{aligned}
 & p \cdot \exp\left(b \cdot n \cdot \mu_F + \frac{b^2}{2} \cdot n \cdot \sigma_F^2\right) - n \cdot \mu_{CO} && \text{e-process} \\
 V = & n \cdot p \cdot b \cdot \mu_F - n \cdot \mu_{CO} && \text{p-process} \\
 & -p \cdot \exp\left(-b \cdot n \cdot \mu_F + \frac{b^2}{2} \cdot n \cdot \sigma_F^2\right) - n \cdot \mu_{CO} && \text{b-process}
 \end{aligned} \tag{5}$$

Equation (5) constitutes a solid foundation to derive solutions for the E-E trade-off and the risk trade-off. It combines different types of customer behaviors and process efficiency on a common theoretical foundation enabling the detailed analysis of the E-E trade-off.

Furthermore, risk in form of the variation of the process fulfillment is also implemented providing the analytical basis for the risk trade-off.

Variable	Definition	Origin
V	Decision value	Value Based Management (Koller et al. 2015)
μ_{CO}	Expected cash outflow per process	Inspired by Bolsinger (2015)
μ_F	Expected degree of fulfillment of	Inspired by Kano et al. (1984)
σ_F^2	Variance of process output	Inspired by Bolsinger (2015)
p	Profitability of satisfaction	Inspired by Gruca and Rego (2005)
b	Customer sensitivity on fulfillment	Inspired by Kano et al. (1984)
n	Process executions per period	Bolsinger (2015)

Table 1 – Overview Variables

IV.1.4 Interpretation and Analyses

IV.1.4.1 Risk Orientation

Based on our analytical framework from the previous section, we can now define the optimal strategic design of business processes with respect to both trade-offs incorporated in our research objective, namely risk- and E-E trade-off. Beginning with the risk trade-off, we can state that BPM primarily advises risk-averse process designs. Theoretical foundations for this one-sided advice come from the statistical theory of variation and from the typical assumption of risk-averse decision-makers in economic research. The statistical theory of variation suggests that process variation causes process outputs to deviate from their target specification and that the elimination of deviations leads to cost savings (Deming 1994). This reasoning is the basis for the popular six sigma approach that demands the continuous reduction of variation as strategic objective. From a more economic view, the typical assumption of risk-averse decision-makers leads to the dominance of risk-averse design objectives (Bolsinger et al. 2011). However, when including the customer perspective as a second analytical lens on the risk trade-off, these results demand further differentiation: The different cash inflow dynamics from excitement, basic and performance processes need to be taken into account. As excitement processes promise extremely satisfied customers for high fulfillments and as they are not exposed to potential disappointments for low fulfillments, an organization faces only upside risk. In this case, risk-taking designs are beneficial as positive extremes are rewarded by additional cash inflows while negative deviances are not punished by lower cash inflows. Correspondingly, more varying excitement processes showing more extreme fulfillments better adopt this asymmetric risk mechanics and thereby show a higher profitability. For basic processes the opposing

argumentation holds. They face extremely disappointed and unprofitable customers for low fulfillments and cannot benefit from profitability increases in the cases of high fulfillments. In other words, basic processes only face downside risk. Risk-averse designs are advantageous as positive extremes are not rewarded by additional cash inflows while negative deviances are punished by lower cash inflows. Consequentially, more stable basic process show a smaller exposure to the described downside risk and promise a higher profitability. Considering performance processes, we can state that the symmetric satisfaction mechanics neither favors a risk-taking nor a risk-averse orientation and that a risk-neutral orientation should be followed.

In order to mathematically prove this argumentation within our framework, we derive the objective functions (equation (5)) with respect to the variance of the fulfillment and show that the derivative (equation (6)) for excitement processes is strictly positive, that the derivative for basic processes is strictly negative and that the derivative for performance processes equals zero indicating risk-taking, risk-averse and risk-neutral designs as beneficial. Accordingly, we can confirm our hypothesis that risk strategy is dependent on the process type.

$$\begin{aligned}
 p \cdot b^2 \cdot n \cdot \sigma_F^2 \cdot \exp\left(b \cdot n \cdot \mu_F + \frac{b^2}{2} \cdot n \cdot \sigma_F^2\right) &> 0 && \text{e-process} \\
 \frac{\partial V}{\partial \sigma_F} = 0 &&& \text{p-process} \\
 -p \cdot b^2 \cdot n \cdot \sigma_F^2 \cdot \exp\left(-b \cdot n \cdot \mu_F + \frac{b^2}{2} \cdot n \cdot \sigma_F^2\right) &< 0 && \text{b-process}
 \end{aligned} \tag{6}$$

For excitement processes, the derivative of the objective function with respect to the fulfillment variance is strictly positive. This is because all parameters are defined on a positive definition range and because the exponential function has a strictly positive value range. For basic processes, the same argumentation holds, but the minus sign makes the derivative strictly negative. As performance processes do not display the fulfillment variance in their value function, the derivative equals zero.

As we intentionally applied the expected value as our valuation function and thereby assumed a risk-neutral decision-maker, we now discuss our results for risk-averse decision-makers. As the process and customer characteristics do not show a risk preference for performance factors, the risk aversion originating from the attitude of the decision-maker becomes decisive. Thus, risk-averse decision-makers should concentrate on risk-averse designs for performance processes. In the case of basic processes, the risk aversion from the customer and process side is reinforced by the decision-maker's attitude and again risk-

averse designs are favorable. For excitement processes, the preference for risk-taking designs is countered by the risk aversion of the decision-maker and we cannot directly make a clear statement. However, we can put forward two qualitative arguments to support risk-taking designs. First, the positive effect of process variance originating from the upside risk of excitement processes exponentially increases process profitability. In the BPM literature, the negative effects of process variance resulting from the decision-maker's risk attitude are often modeled as linear and thereby less influential than the exponential benefits from risk-taking designs on the customer side (see e.g. Bolsinger et al. 2011; Buhl et al. 2011). Second, economic theory often interprets risk as two-sided and thereby combines upside and downside exposures while neglecting the one-sided potential of the case at hand. Thus, the typical conceptualization of risk aversion does not fit the conditions of excitement processes. More differentiated interpretations of risk can be found in advanced performance measures like the Shadwick Omega (Shadwick and Keating 2002) which directly addresses this conceptual drawback. On this basis, we argue that the interpretation of risk aversion is not suitable for excitement processes and state that the preference of risk-taking designs also holds for risk-averse decision-makers. Summing all up, we showed that organizations should follow an ambidextrous design strategy with respect to the risk orientation of their processes. For excitement processes, risk-taking designs are beneficial as they better absorb the asymmetric profitability mechanics. For basic and performance processes, the more traditional, risk-averse orientation can be maintained.

IV.1.4.2 Experience-Efficiency Trade-Off

Existing redesign approaches like for example Limam Mansar et al. (2009) or the Devil's Quadrangle from Brand and van der Kolk (1995) put operational process performance and therefore efficiency as their central objectives. Redesign approaches from the research stream of value-based BPM strongly request the additional consideration of cash inflows but do not explicitly include customer behavior as the decisive force. In this section, we relate process efficiency represented by the cash outflows and customer orientation represented by the cash inflows within our framework to fill this research gap.

Again the different mechanics of basic and excitement processes with their asymmetric customer perceptions on the one side and the linear perception of performance processes on the other side demand the ambidexterity of design objectives. Analyzing the different structures qualitatively, we derive three key-results: First, organizations need to ensure a saturation degree of fulfillment μ_{SAT} for basic processes. In other words, customer-centric

designs are favorable until very disappointed customers are prevented. Once that saturation fulfillment is reached, efficient designs become more favorable even if the fulfillment stays moderate. A generic design strategy would be: “Prevent extreme disappointments at possibly low process costs”. This two-sided strategy is a direct consequence from the asymmetry of the customer behavior. As customers of basic processes become only disappointed for large underperformances, only these extreme cases have to be prevented (Kano et al. 1984). In all other cases, efficiency promises to be more valuable than additionally boosting process fulfillment. Second, excitement processes need a minimum level of fulfillment μ_{MIN} to prefer customer-centricity over efficiency. In the right accelerating branch of the satisfaction curve, i.e. in the area of high over-fulfillment, (see Figure 1) customer-centric designs unfold their true potential. According to Kano (1984), true excitement requires unexpectedly high fulfillments. If customer-centric designs cannot bring the process in this excitement area, efficient alternatives are the better strategy. Third, the effects of customer-centricity and efficiency are about equally strong across different levels of fulfillment for performance processes.

In order to show these qualitative propositions mathematically, we introduce the experience-efficiency-ratio (E-E-ratio) as the relation between the derivative of the objective function with respect to the expected degree of fulfillment and its derivative with respect to the expected cash outflows. If processes exhibit an E-E-ratio larger than one, their values react more sensitively on customer-centric redesigns. For ratios smaller than one, efficient redesigns become more valuable. This inequality can be rewritten into the minimum level of fulfillment for excitement processes and the saturation level of fulfillment for basic processes.

$$\begin{aligned}
 & p \cdot b \cdot \exp\left(b \cdot n \cdot \mu_F + \frac{b^2}{2} \cdot n \cdot \sigma_F^2\right) > 1 && \text{e-process} \\
 \rightarrow \mu_F > -\frac{\ln(p \cdot b)}{b \cdot n} - \frac{b}{2} \cdot \sigma_F^2 = \mu_{MIN} &&& \\
 E - E - & && \\
 ratio = & p \cdot b > 1 && \text{p-process} \quad (7) \\
 & p \cdot b \cdot \exp\left(-b \cdot n \cdot \mu_F + \frac{b^2}{2} \cdot n \cdot \sigma_F^2\right) > 1 && \text{b-process} \\
 \rightarrow \mu_F < \frac{\ln(p \cdot b)}{b \cdot n} + \frac{b}{2} \cdot \sigma_F^2 = \mu_{SAT} &&&
 \end{aligned}$$

Further substantiating these findings, we conduct sensitivity analyses of the E-E-ratio against customer sensitivity b and the degree of expected fulfillment μ_F . In a first step, we set up a basic calibration for all variables of the E-E-ratio (cf. Table 2 – basic calibration). The parameter values of this calibration are in a common range and enable a comparable

illustration of the mathematical results. Naturally, values are strongly dependent on the investigated industry and organizations, so we decided to choose moderate or average values for each parameter. Thus, as values for p and n linearly influence the E-E-ratio, we standardize them to 100. Furthermore, μ_F and σ_F can take on values between 0 and 1, thus we took moderate values as starting point for our sensitivity analysis to allow for adequate variations into both directions. Customer sensitivity is probably most difficult to operationalize (we add a corresponding discussion in the conclusive section). Analytically, the form of the Kano functions resemble exponential utility functions from VBM. Accordingly, we took a plausible value inspired by values reported in VBM literature (Bolsinger 2015; Buhl et al. 2011).

customer profitability p	customer sensitivity b	number of customers n	expected fulfillment μ_F	std. deviation of fulfillment σ_F
100	0.015	100	0.4	0.2

Table 2 – basic calibration

For customer sensitivity b we started with 0.005 slightly increasing in steps of 0.0001 up to 0.015. Figure 3 shows that customer-centric designs gain importance with more sensitive reactions of customers on fulfillment. The less sensitive customers react on a given level of fulfillment, the less desirable are customer-centric process designs, as customers do not reward the invested effort with higher satisfaction and profitability. This is directly reflected by the linear increase of the E-E-ratio for performance processes. For excitement processes, customer-centric designs are highly recommended from a minimum level of customer sensitivity on. Thus, organizations should aim at high fulfillments and even accept drawbacks in process efficiency, if the customer sensitivity is that high, that customers really reward their redesign efforts with excitement and therefore profitability. Basic processes have to be efficient as the E-E-ratio stays smaller than one. In other words, basic processes should follow lean and efficient designs as the marginal costs of non-fulfillment are always lower than the marginal process costs. This is because the expected degree of fulfillment is with 0.4 in a moderate range, preventing extreme disappointments and favoring efficiency. Overall the illustration transports two key messages: First, higher customer sensitivities favor customer-centric designs. Second, with moderate expected fulfillments, excitement processes should be designed to excite and basic processes should be designed possibly efficient.

In a second step, we vary the degree of fulfillment μ_F (values ranging from 0 to 0.9 with steps of 0.01) to illustrate the asymmetry of optimal process designs across different degrees of current fulfillment (cf. Figure 4). Whereas our first analysis indicates, that efficient process designs are favorable for basic processes in any case, we can now refine this recommendation in line with our mathematical results. Indeed, our second analysis illustrates the saturation degree of fulfillment which should be reached by customer-centric designs. From this saturation level on, organizations should focus on efficient process design. Although concrete values for the saturation level strongly depend on the chosen customer sensitivity in the basic calibration, we can generally state, that organizations should fulfill the saturation level for basic processes possibly efficient. As already shown mathematically in equation 7, the optimal design orientation of performance processes, does not vary across different degrees of fulfillment. Finally, excitement processes should prefer customer-centric designs with higher fulfillments. This can be substantiated by the parametrization of customer sensitivity rate in our basic calibration. As the chosen customer sensitivity makes excitement possible, efforts for higher fulfillment and thus higher customer satisfaction pay out.

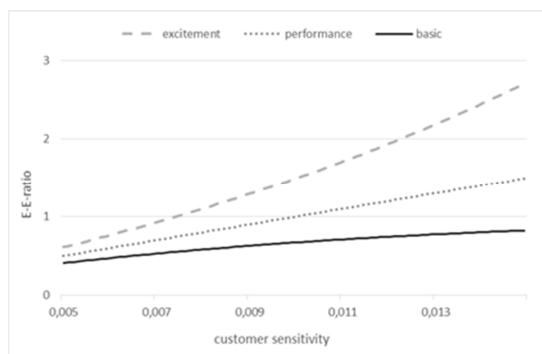


Figure 3: Variation of customer sensitivity of fulfillment

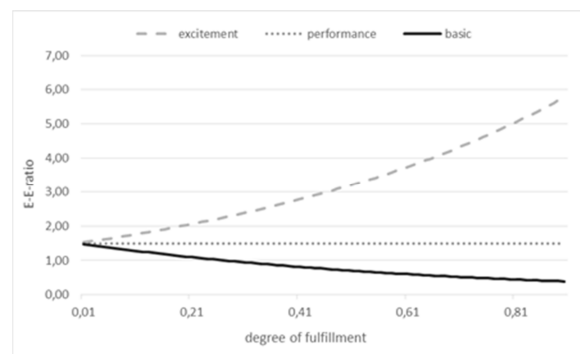


Figure 4: Variation of degree of fulfillment

The presented theoretically based framework is by nature a bit abstract and up to now not tested empirically. Thus, we want to illustrate the practical relevance, using an example from the automotive industry. For our example, we draw back on a comparison of the two car manufacturer Toyota and BMW. The Japanese car manufacturer Toyota is actually the largest car manufacturer in the world as measured by cars produced in 2015 (Schmitt 2016) and therefore produces *mass-market vehicles*. In contrast, BMW is a bit more focused on the *luxury vehicle market*. Accordingly, the widespread image of Toyota is a – compared to the German manufacturer BMW – auspicious car manufacturer, but still producing good quality cars. Deriving from these images, Toyota's mass-market customers can be declared as

comparably easy, whereas BMW's luxury customers are more demanding. Besides the customer side, we need to investigate the process side in order to apply the presented framework. Therefore the production process fits well to illustrate the mechanism of the framework. As high fulfillment in the production process leads to a high car quality and therefore higher customer satisfaction, whereas low fulfillment causes low car quality and dissatisfaction, we declare it as a performance process.

Starting with Toyota, we recognize a consequent lean six sigma approach in its production process (Pepper and Spedding 2010), combining efficient process design with a certain level of quality control. Measured by the American Customer Satisfaction Index (ACSI), this strategy pays out as Toyota holds the second rank for customer satisfaction in the category "mass-market vehicles" in the ACSI Automobile Report (American Customer Satisfaction Index 2016). This is in line with the proposed design strategy of our framework which is a risk-averse and exploitative design for performance processes with easy customers. In contrast, BMW with demanding luxury vehicle customers should focus more on the customers in order to meet their needs. Thus, BMW has a more complex production process, offering greater variety of interior and equipment options. Additionally, strict quality controls are necessary. Exactly this strategy is proposed by our model recommending a risk-averse and explorative strategy for performance processes with demanding customers. Again, the strategy pays out for BMW with the second rank for customer satisfaction in the category "luxury vehicles" (American Customer Satisfaction Index 2016). In order to validate these results, we propose to conduct a cross-case analysis in a next step.

IV.1.5 Conclusion and Discussion

At the center of this paper stands the necessity of a two-dimensional, ambidextrous strategy for business process design. Thus, organizations have to find the right balance between risk-taking and risk-averse process designs (risk trade-off) as well as between explorative and exploitative process designs (E-E trade-off). Even if an organization accepts the necessity of design ambidexterity, the key problem is still to decide which of the archetype designs their processes should follow. This decision is very complex as it requires detailed knowledge about customer and process behavior. Moreover, it needs to be taken for every process separately. Given this complexity, organizations have a deep need for concrete, practical guidance on how to decide the strategic orientation of their business processes.

In order to meet this requirement the presented framework integrates the customer and the process perspectives to provide a holistic understanding about the interplay of the trade-offs.

We connect established theories from BPM in form of value-based BPM and CRM in form of the Kano model, incorporating a strong VBM focus as our methodological bracket. In doing so, we do not claim to give in-depth guidelines for the design of a singular process, we rather aim at an improved understanding of the decisive forces and at providing high-level design guidelines for all Kano process types. Therefore, the contribution of our framework is two-fold. First, we enhance existing redesign approaches like Limam Mansar et al. (2009) and others who operate on a given set of strategic redesign objectives. These approaches focus on prioritizing different redesign ideas on a defined strategic evaluation scheme. With deriving such an evaluation scheme, we complement existing approaches to a holistic redesign framework. Second, we support the rethinking of the BPM community in the direction of ambidextrous BPM as initiated by Rosemann (2014). The predominant strategic objective of BPM is improving process performance which typically follows a more efficiency-orientated connotation. We demonstrate that customer orientation and the inclusion of the customer perspective is a second strategic objective that should stand equally next to operational performance.

Based on our framework, we prioritize design strategies with respect to different process and customer characteristics. For business processes, current expected fulfillment, the variance of current fulfillment and current efficiency are the decisive characteristics. On the customer side, customer sensitivity towards fulfillment and the classification of their perceptions as excitement, basic or performance processes are relevant. Our comparative analyses propose risk-taking designs for excitement processes and risk-averse designs for basic and performance processes. The basic reasoning behind this result is to leverage the asymmetric upside potential of excitement process to excite while simultaneously managing the risk of under-fulfillment for performance and basic processes. For the E-E trade-off, we conclude customer-centric designs for excitement processes with moderate and high fulfillments to fully exploit their upside potential. Furthermore, we propose efficient designs for excitement processes with low fulfillment, as efficiency savings outweigh further selling potential stimulated by an increased customer satisfaction. For basic processes, we propose customer-centric designs until an acceptable fulfillment is promised and the risk of extreme disappointments is mitigated. Once such a saturation degree of fulfillment is ensured, we recommend switching to efficient design alternatives to achieve this saturation state as efficient as possible. For performance processes, our framework gives the differentiated advices to use efficient designs in case of “easy” customers, which are customers that are not sensitive to (non)-fulfillment of their needs, whereas customer-centric designs are

promising for sensitive customers that strongly react on good or bad performances. Table 3 summarizes our results and proposes which of the 4 archetype strategies should be used dependent on process characteristics. The 4 archetype strategies are: 1) *risk-taking and efficient*, 2) *risk-taking and customer-centric*, 3) *risk-averse and efficient* and 4) *risk-averse and customer-centric*.

	Low fulfillments	Moderate fulfillments	High fulfillments
Basic processes	4) <i>Risk-averse and explorative design</i>	3) <i>Risk-averse and exploitative design</i>	3) <i>Risk-averse and exploitative design</i>
Performance processes with “easy” customers	3) <i>Risk-averse and exploitative design</i>	3) <i>Risk-averse and exploitative design</i>	3) <i>Risk-averse and exploitative design</i>
Performance processes with “demanding” customers	4) <i>Risk-averse and explorative design</i>	4) <i>Risk-averse and explorative design</i>	4) <i>Risk-averse and explorative design</i>
Excitement processes	1) <i>Risk-taking and exploitative design</i>	2) <i>Risk-taking and explorative design</i>	2) <i>Risk-taking and explorative design</i>

Table 3: Process design principles

Readdressing our primary research objective of supporting practical decision-makers in defining the proper design strategy, we now discuss the applicability of our model, especially the gathering of the required input data. Whereas organizations may obtain typical process data on expected process cash outflows or fulfillment (e.g. process error rate) from their ERP system or the accounting department, information on customer behavior needs a more thorough discussion. As for the most important information, organizations need to determine as what Kano type customers perceive their process outputs. Therefore, a customer survey needs to be conducted. For a proper classification method as excitement, basic or performance process, we refer to the questionnaire of Matzler et al. (1996). Concerning customer profitability and the number of customers, CRM systems might provide a proper orientation. The most abstract variable is customer sensitivity towards fulfillment. Calibrating this variable should either be achieved in line with the conducted

customer survey in form of scenario descriptions or by expert estimations. However, customer sensitivity only matters for performance processes where it decides between exploitative and explorative design strategies. We suggest that practitioners should trust in their feelings whether they have demanding or easy customers and decide accordingly. Addressing a second point of applicability, we want to discuss the practical relevance of our model as a *black-box approach*. In BPM, academia typically differentiates three kinds of redesign approaches: creative, structured and enhanced structured (Limam Mansar and Reijers 2005). The creative approach identifies new process designs relying on brainstorming sessions of human decision-makers. The degree of improvement in this approach thereby heavily relies on the intuition of decision-makers and leverages their knowledge bases. The strengths of this approach lie in the high creativity and the innovative power allowed to the decision-makers, but often leads to biased prioritizations (Limam Mansar et al. 2009). The structured approach uses quantitative models for redesigning processes. Although this approach is less biased and avoids neglecting promising design candidates, it is less creative and more industrial. As an intersection between both extremes, Limam Mansar et al. (2009) propose an improved redesign process. They propose a two-step approach, where quantitative models make propositions which are then evaluated by a design committee (Limam Mansar et al. 2009). This is also where we see the strength of our model. It should not be applied blindly, but the proposed design strategy should be validated by the process decision-makers. The model should help and support decision-makers to understand the interplay of different effects to provide them a reasonable basis for making good redesign decisions.

Our framework and our managerial implications are beset with limitations that demand future research. First, we restricted our framework to so called primary activities (Porter and Millar 1985), also known as core processes (cf. Dumas et al. 2013) which are business processes with direct interfaces to the end-customers of an organization. As a result, our framework is not directly applicable for support and management processes which aim at ensuring the proper functioning of primary activities. To transfer our results on these types of processes, their insuring effects and their perceptions by the end-customers need to be quantified. However, given the indirectness of effects a strong dominance of efficient designs is to be expected. Second, we cannot depict robust values for the saturation and minimum degree of expected fulfillment to completely describe the conditions for customer-centric designs. Although, we can conceptually and analytically prove the existence of these conditions and determine the asymmetric customer behavior as comprehensive reason,

further empirical research is needed to provide decisive values. As we can determine customer sensitivity fulfillment variance, profitability and the number of executions as influencing variables on the degrees of fulfillment, we provide a suitable base for future empirical analyses. Third, solving the question about proper strategic orientation for redesign initiatives is only one task in the complete redesign process (Limam Mansar et al. 2009). Other tasks like the identification of redesign patterns or their evaluation against the strategic objectives is outside our research scope. We encourage future work to address this drawback and to implement our strategic reasoning into existing redesign approaches. Thereby, a holistic redesign tool could emerge. Fourth, the model operates on a kind of consensus of customer base on the classification of the process into the three categories. Criticizing this ternary classification is reasonable but it represents the essential of the acknowledged Kano model. Besides, our model could be adjusted to more flexible classifications. Therefore, users need to divide their customer base into three customer types respective to their attitudes toward the process output, parameterize our model for all three process types and build the weighted average of the intermediate process values with respect to the proportion of the customer types on the entire customer base. If one customer type dominates the other types, let's say with a proportion of 75% or more, users can use the respective dominant class as representative for the entire base.

Summing up, there is still need for further research at the interface of BPM and CRM. However, the mindset of a strong value focus in designing business processes combined with the knowledge about the presented trade-offs and its implications on design principles, empowers organizations to improve their value on the long run.

IV.1.6 References

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IV.2 Design it like Darwin – A Value-based Application of Evolutionary Algorithms for Proper and Unambiguous 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, this paper applies 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 maintaining well-performing design structures and continuously evolving new designs. Beginning with describing process elements and their characteristics in matrices to aggregate process information, the 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.

IV.2.1 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. This paper follows 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).

Considering the success of computational intelligence (CI) in design and optimization problems from the business world, this paradigm seems promising. 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 this paper investigates the following research question: *How can organizations leverage CI to redesign their processes while accounting for the essential process elements?*

In order to address this research question, this paper develops an EA-application in a broader sense and translates 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 process elements (e.g., activities, objects and their logic connectivity), which is the key challenge in the translating part. As research method, design science research (DSR) paradigm is chosen as EAs fulfill the criteria of a valid DSR artefact type (March and Smith 1995). As justificatory knowledge, this study draws from a 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, VBM serves for evaluating 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. Section 2 outlines the development of computational intelligence in BPM to position the contribution of our work. Section 3 derives design objectives from the business requirements (*objectives of a solution*) and provides relevant justificatory knowledge. Section 4 outlines the research idea and evaluation strategy. Section 5 introduces the design specification of the EA application (*design and development*). Section 6 reports on our evaluation activities (*evaluation*). The authors conclude in section 7 by pointing to limitations and future research possibilities.

IV.2.2 Computational Intelligence in the History of BPM

BPM is an integrated system for handling organizational performance, regulatory compliance, and service quality by managing processes (Dumas et al. 2013; Hammer 2015). In other words, it 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). Following the historic overview on the evolution of BPM by van der Aalst (2013), the role of CI goes back to the process improvement postulation in the mid-nineties (Hammer and Champy 1993) when BPM finally found its way into information systems (IS) research. 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 increasingly shifts from an operational to an analytical orientation. With a broader scientific horizon, it now includes controlled process execution and process redesign.

Concerning the 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 generation 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 realization 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: 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.

Briefly, practitioners and academia have recognized the importance of tool-support for process redesign and provide first approaches that use artificial intelligence algorithms. Nevertheless, we can justify applications of CI in BPM as meaningful research problem: Although IT and computational intelligence already find applications in the design of new process alternatives and help to make the design process more easily, more cost-effectively, quicker, more systematically, and more robust against subjective vagueness, the technical task of generating new process designs is still in its infancy (Limam Mansar et al. 2009). This paper addresses this research gap by enhancing existing approaches by implementing additional process elements, establishing unambiguous redesign objectives to deal with the increasing complexity of today's processes.

As the further development of the existing approaches intends to design and implement a new and innovative artefact (e.g., models, methods, constructs, instantiations, and design theories or in our case computational intelligence tools for process redesign) (Hevner et al. 2004; March and Storey 2008), it could follow the design science research (DSR) paradigm as theoretical fundament (March and Storey 2008). The DSR methodology as per Peffers et al. (2007) proceeds in six steps: *identification of and motivation for the research problem*, *definition of the objectives of a solution*, *design and development*, *demonstration*, *evaluation*, and *communication*. As we already identified and motivated a meaningful DSR problem, we proceed with step 2.

IV.2.3 Design Objectives and Justificatory Knowledge

In order to accomplish the second step of DSR (Peffers et al. 2007), we need to derive design objectives ((O.1) – (O.3)) from justificatory knowledge. In general, design objectives help to assess whether an artefact properly solves the identified research problem. As

justificatory knowledge, we refer to BPM and to VBM. As processes and their elements are the essentials of process redesign, we define the first design objective:

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

A process is defined as a collection of inter-related events, activities, and decision points that involve a number of actors (or resources) 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 executions 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. 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, with design objective O.1, the combinations of activities, objects, conditions, etc. form realistic process designs with different levels of complexity.

As the implemented design in turn influences the overall process performance, the design candidates provide a basis for prioritization (Limam Mansar et al. 2009). To provide concrete guidance for redesign initiatives and to support a clear corporate decision-making, we define the second design objective:

(O.2) **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.

In the context of BPM, organizations normally 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 prevent from ambiguous design prioritizations each fulfilling another objective.

To resolve the partly conflicting nature of these performance dimensions via integrated performance indicators, process decision-making at least devoted increasing attention to value-based management (vom Brocke and Sonnenberg 2015). It is the guiding paradigm of corporate decision-making in economic research and practice (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 – and consequently as design objective O.2, 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).

The most prominent methods in BPM that leverage the essentials of VBM for solving BPM problems are goal-oriented BPM (Neiger and Churilov 2004a), value-focused BPM (Neiger and Churilov 2004b, Rotaru et al. 2011), value-driven BPM (Franz et al. 2011), value-oriented BPM (vom Brocke et al. 2010), and value-based BPM (Bolsinger 2015). Particularly, process-related decisions based on value-oriented or value-based BPM solve the problem of the partly conflicting, multi-objective nature of performance dimensions by compiling it into the integrated, single-objective measure of a process' value contribution (Buhl et al. 2011). Both methods also consider cash flows and the time value of money. Whereas, value-oriented BPM has a stronger focus on the financial perspective and the pure cash flows in terms of the payment structure (Bolsinger 2015), value-based BPM uses the valuation functions as analytical lenses to compare process alternatives (Bolsinger 2015). In line with our intention to prioritize design alternatives, value-based BPM is qualified as guiding paradigm. Not least, ever more approaches adopt value-based BPM to support process design in an economically well-founded manner while comparing design alternatives and/or proposing improvement recommendations (Bolsinger 2015; Bolsinger et al. 2015; vom Brocke et al. 2010). Further approaches integrate the financial and non-financial performance effects that capture how work is organized and structured within the central measure of process cash flows (Afflerbach et al. 2014; Linhart et al. 2015a; Linhart et al. 2015b). As the value contribution of processes depend on the tasks and paths included in process models as well as on the tasks' monetized performance effects, methods such as that proposed by Bolsinger (2015) help aggregate multi-dimensional task and path characteristics to cash flows.

As the overall process performance varies over time owing to the constantly changing environment and, consequently, the implemented process design has to keep pace, we define the third design objective:

- (O.3) Evolutionary Redesign: Computational redesign should follow an evolutionary logic to be in line with known best practices and to reduce organizational resistance.

Process redesign as the most important and valuable phase of the BPM lifecycle (Zellner 2011) evolved as an everyday task (Doomun and Vunka Jungum 2008). In regards to these redesign initiatives, companies face a technical and a socio-cultural challenge (Reijers and Limam Mansar 2005). 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. Design objective O.3 addresses both perspectives of the socio-economic challenge in a dynamic environment. As most accepted approach for process redesign (Dumas et al. 2013), the BPM lifecycle and its evolutionary, incremental procedures represent a suitable foundation for the DSR artefact.

IV.2.4 Research Idea and Evaluation Strategy

In the design and development phase of our DSR project (cf. Peffers et al. 2007), 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 EA customization 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 (sections 5.1). We then proceed with the problem representation and bring processes to the computational level based on LISt programming (LISP) and attribute matrices (sections 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 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 implemented the artefact in Microsoft Excel (MS Excel) and Visual Basic for Applications (VBA).

IV.2.5 Computational Process Redesign

We use the concepts of CI to design an algorithm supporting the process redesign problem. To match CI capabilities as problem solution and BPM requirements as problem domain, we are confronted with decisions about the appropriate algorithm, about design elements and about 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 design solutions. Constructional aspects relate to the population concept and the evaluation of solutions.

IV.2.5.1 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. As an intermediate step, we draw parallels to the biological evolution (Darwin 1859; Mendel 1866) as basis for the identification of a nature-inspired problem solution that follows an evolutionary logic to be in line with the well-known BPM lifecycle as problem domain and to reduce organizational resistance (see design objective O.3).

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 objects. 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 2*. 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 natural 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.

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. According to our theoretical reasoning, we introduce the EA approach to BPM (see outer part of *Figure 2*). Thereby, the fundamental procedure of the EA is similar to the simplified procedure of the BPM lifecycle – even though the EA actually only supports the one phase of process redesign in the BPM lifecycle.

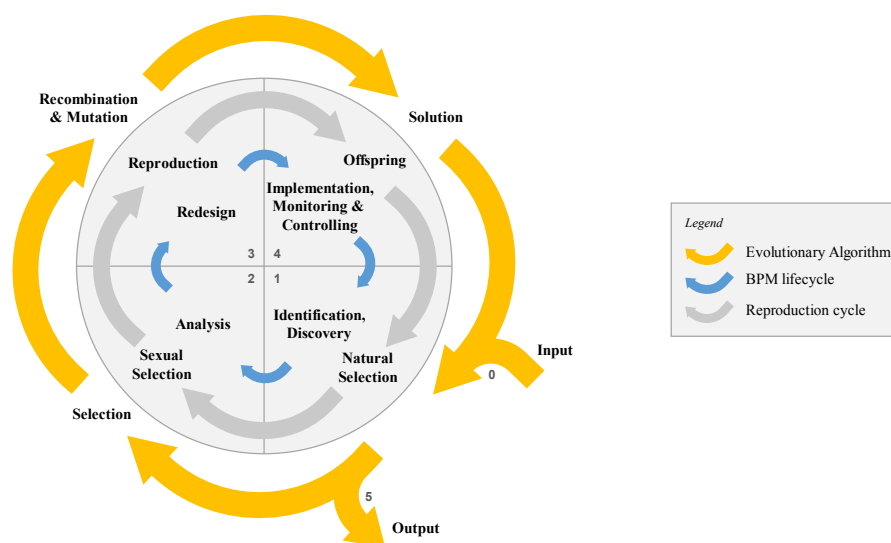


Figure 2. Matching EA as problem solution to BPM as problem domain considering reproduction

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.3). 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.

IV.2.5.2 Translating from Real-world to Computational World

To provide a better understanding of the design decisions – and the constructional aspects in section IV.2.5.3 – we briefly introduce an example process. We refer to this process whenever necessary and use it for evaluation purposes in section IV.2.6.2. 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 3* sketches the design in BPMN notation.

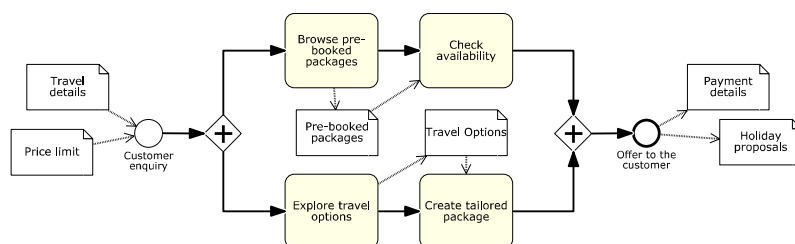


Figure 3. Travel Agent Process

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 from real-world to computational world. According to its definition, a process or its design respectively is a combination of finite elements. 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 elements but also about their characteristics. Therefore, we divide process designs into their basic elements: activities, connections, and routing decisions. In order to fulfil design objective O.1, we implement five matrices: the *activity-attribute matrix*, the *object-attribute matrix*, the *activity-input matrix*, the *activity-output matrix*, and the *activity-process-attribute matrix*.

The first two matrices describe the attributes of activities and objects. 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 objects. 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 $\mu_{a_x} = E[\widetilde{CF}_{a_x}]$ and the process risk by the variance of cash flows $\sigma_{a_x}^2 = Var[\widetilde{CF}_{a_x}]$. Both distribution parameters may be gathered from historical data or expert estimates. *Table 2* shows the activity list for our travel agent process with two alternative forms for each activity shown in *Figure 3*, e.g., a_1 and a_2 are alternatives for the activity *Browse pre-booked packages*. 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, we can easily infer the cash flows as process costs by monetizing execution times.

No.	Function	μ_{a_x}	$\sigma_{a_x}^2$
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

Table 2. Activity-Attribute Matrix

The *objects-attribute matrix* lists all objects that could be used during process execution. In general, most objects 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 *object-attribute matrix* denotes objects (represented by the variable o_x) in the rows as process input or output and assigns economic attributes in the columns (see *Table 3*). If an object is denoted as process input, the total cash outflows required for the provision of the object is the corresponding economic attribute from VBM. If an object 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 objects, i.e., pre-booked packages and travel options, are necessary to depict a proper sequence flow. As these objects are neither process input nor process output, they do not need economic attributes.

No.	Description	Type	Process Input	Process Output	Price
o_1	Travel details	Information	Yes	No	0
o_2	Price limit	Information	Yes	No	0
o_3	Pre-booked Packages	Information	No	No	0
o_4	Travel options	Information	No	No	0
o_5	PBP: Holiday proposals	Information	No	Yes	20,00
o_6	PBP: Payment details	Information	No	Yes	25,00
o_7	TO: Holiday proposals	Information	No	Yes	20,00
o_8	TO: Payment details	Information	No	Yes	25,00

Table 3. Object-Attribute Matrix

The other matrices describe the relationships of objects and determine 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., object o_1 is output from a_1 and 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 object flows through the process design. According

to process input and output (see *object-attribute* matrix), not all objects are both input and output in the same process design. For the chosen example, *Table 4a* and *Table 4b* show the input-output-relationships of activities and objects for the chosen example and, thus, the different alternatives for specific inputs or outputs. As a_1 and a_3 use the same input (i.e., o_1 and o_2) while creating differing outputs (i.e., o_3 for a_1 and o_4 for a_3), the information in these matrices already illustrate potential, parallel executions (e.g., both a_1 and a_3 could start at the same time when o_1 and o_2 are provided as process input). On a technical level, these matrices implement logical restrictions to our optimization problem: A process design is only feasible if the input for each activity has been provided as process or activity input in advance.

a) Activity-Input Matrix					B) Activity-Output Matrix						
	o_1	o_2	o_3	o_4		o_3	o_4	o_5	o_6	o_7	o_8
a_1	1	1	0	0	a_1	1	0	0	0	0	0
a_2	1	1	0	0	a_2	1	0	0	0	0	0
a_3	1	1	0	0	a_3	0	1	0	0	0	0
a_4	1	1	0	0	a_4	0	1	0	0	0	0
a_5	0	0	1	0	a_5	0	0	1	1	0	0
a_6	0	0	1	0	a_6	0	0	1	1	0	0
a_7	0	0	0	1	a_7	0	0	0	0	1	1
a_8	0	0	0	1	a_8	0	0	0	0	1	1

Table 4. Activities in relation to objects

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_{xy}) 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 their execution probabilities. For ordinal and 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 (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). In this case, the decisive value is the number of stars. Thus, there are five distinct attribute forms from 1-star-rating to 5-star-rating. As we assume that the relatively most hotels have a 3-star-rating, this value has the highest probability (i.e., 50%). The effect of process attributes on the routing decisions can be shown by activities a_7 and a_8 . Even though both a_7 and a_8 are two alternatives for the same activity *Create tailored package* (see Table 2) while using the same input (i.e., o_4 ; see Table 4a) and serving the same output (i.e., o_7 and o_8 ; see Table 4b), they would not be alternatives any more as both do not cover all required attribute values.

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).

Process Attribute	Hotel Category (d_1)				
	★	★★	★★★	★★★★	★★★★★
Attribute Form	2,5%	17,5%	50%	25%	5%
Probability	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

Table 4: Activity-Process-Attribute Matrix

Following the object perspective and to ensure proper object 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 activity 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 r . Technically, we use the following notation: $c_x = d_x(v_{c_x}; r_{c_x})$. To conclude a process design, we surround it with angle brackets. *Table 5* summarizes the basic patterns of connections and activities our EA application is able to process.

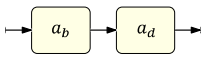
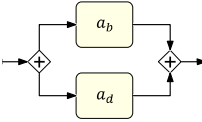
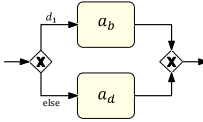
Combination Form	Sequence	Concurrency	Exclusive split
EA notation	a_b, a_d	$AND(a_b; a_d)$	$XOR(d_1(v_{c_1}; r_{c_1}); a_b, a_d)$
BPMN 2.0 notation			

Table 5. Basic patterns of activity combinations.

Basically, any combination of those patterns, also nested combinations, may appear in process designs. *Figure 4* 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_3 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.

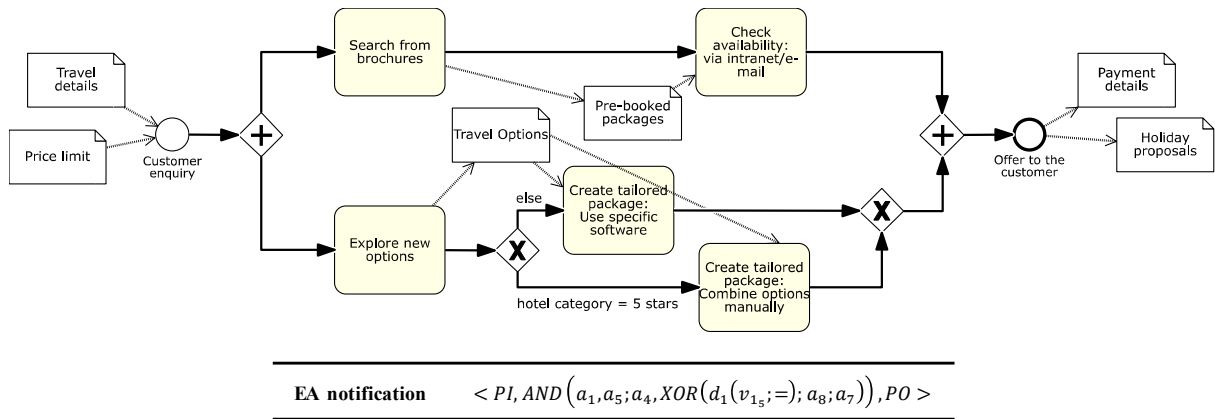


Figure 4. Example process in EA notification

IV.2.5.3 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.

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 pre-defined 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 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.

$\langle PI, AND(a_1, a_5; a_4, XOR(d_1(v_{15}; =); a_8; a_7)), PO \rangle$	<i>(Status quo)</i>
$\langle PI, a_1, a_2, a_3, a_4, PO \rangle$	
$\langle PI, a_1, a_4, a_6, a_8, PO \rangle$	
$\langle PI, a_1, a_3, a_4, a_7, PO \rangle$	
$\langle PI, a_3, a_6, a_7, a_8, PO \rangle$	

Table 6. Initial Population

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 object 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 high performance.

Table 7 demonstrates the stepwise application of the repair mechanism to the first random selection of the initial population in *Table 2*. For o_7 and o_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.

(1) Check Process design for missing output:	$\langle PI, a_1, a_2, a_3, a_4, PO \rangle$
(2) Add activity that provides o_8 :	$\langle PI, a_1, a_2, a_3, a_4, a_8, PO \rangle$
(3) Add further activity that provides o_8 , as existing do not cover all attributes:	$\langle PI, a_1, a_2, a_3, a_4, a_7, a_8, PO \rangle$
(4) Add activity that provides o_6 :	$\langle PI, a_1, a_2, a_3, a_4, a_5, a_7, a_8, PO \rangle$
(5) Repeat the steps for all other objects:	$\langle PI, a_1, a_2, a_3, a_4, a_5, a_7, a_8, PO \rangle$
(6) Erase activities that do not contribute to the production of the process output:	$\langle PI, a_1, a_2, a_3, a_4, a_5, a_7, a_8, PO \rangle$
(7) Arrange activities:	$\langle PI, AND(XOR(d_1(v_{12}; =); a_1; a_2), a_5; XOR(d_1(v_{14}; =); a_3; a_4), XOR(d_1(v_{15}; =); a_8; a_7)), PO \rangle$

Table 7. Step by step guide for the repair mechanism

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.3). These requirements are fulfilled by considering three central variables: The expected net present value of process cash flows $\mu_{NPV} = E[\widetilde{CF}_{NPV}]$ as a measure of efficiency and effectiveness, the uncertainty of those cash flows represented by their expected variance $\sigma_{NPV}^2 = Var[\widetilde{CF}_{NPV}]$ as a measure of risk and the risk aversion of the decision-maker α . It is defined as:

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

Whereas the risk aversion α 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).

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

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-attribute-matrix* and depends on the gateways that define the paths along which a process design can be traversed.

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

$$(5) \quad \sigma_p^2 = -\mu_p^2 + \sum_{d=1}^D (\sigma_{a_x}^2 + \mu_{a_x}^2) \cdot p_{a_d} + 2 \cdot \sum_{d=1}^{D-1} \sum_{b=d+1}^D \mu_{a_d} \cdot \mu_{a_b} \cdot p_{(a_d, a_b)}$$

In our example, applying the repair mechanism to the initial population leads to five feasible process designs (See *Table 8*). The values of the fitness function with $I = 0$, $T = 5$, $i = 2.5\%$, $n = 100$, and $\alpha = 0.05$ are also shown.

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

Table 8. Fitness values of the "repaired" initial population

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 6 provides exemplary tournament selections with the winner marked in bold.

Exemplary tournament selection with number of competitors = 4	Exemplary tournament selection with number of competitors = 2
$\langle PI, AND(a_1, a_5; a_4, XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$	$\langle PI, AND(XOR(d_1(v_{12}; =); a_1; a_2), a_5; XOR(d_1(v_{12}; =); a_3; a_4), XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$
$\langle PI, AND(XOR(d_1(v_{12}; =); a_1; a_2), a_5; XOR(d_1(v_{12}; =); a_3; a_4), XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$	$\langle PI, AND(a_2, a_6; a_3, XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$
$\langle PI, AND(a_1, a_5; XOR(d_1(v_{12}; =); a_4; a_3), XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$	
$\langle PI, AND(a_2, a_6; a_3, XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$	
Exemplary tournament selection with number of competitors = 3	Exemplary tournament selection with number of competitors = 5
$\langle PI, AND(a_1, a_5; a_4, XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$	$\langle PI, AND(a_1, a_5; a_4, XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$
$\langle PI, AND(a_1, a_6; a_4, XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$	$\langle PI, AND(XOR(d_1(v_{12}; =); a_1; a_2), a_5; XOR(d_1(v_{12}; =); a_3; a_4), XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$
$\langle PI, AND(a_1, a_5; XOR(d_1(v_{12}; =); a_4; a_3), XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$	$\langle PI, AND(a_1, a_6; a_4, XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$
$\langle PI, AND(a_1, a_5; XOR(d_1(v_{12}; =); a_4; a_3), XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$	$\langle PI, AND(a_1, a_5; XOR(d_1(v_{12}; =); a_4; a_3), XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$
	$\langle PI, AND(a_2, a_6; a_3, XOR(d_1(v_{12}; =); a_8; a_7)), PO \rangle$

Figure 5. 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.

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 6*). Otherwise, the parents exchange one activity for another (see ① in *Figure 6*). 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 6*). 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.

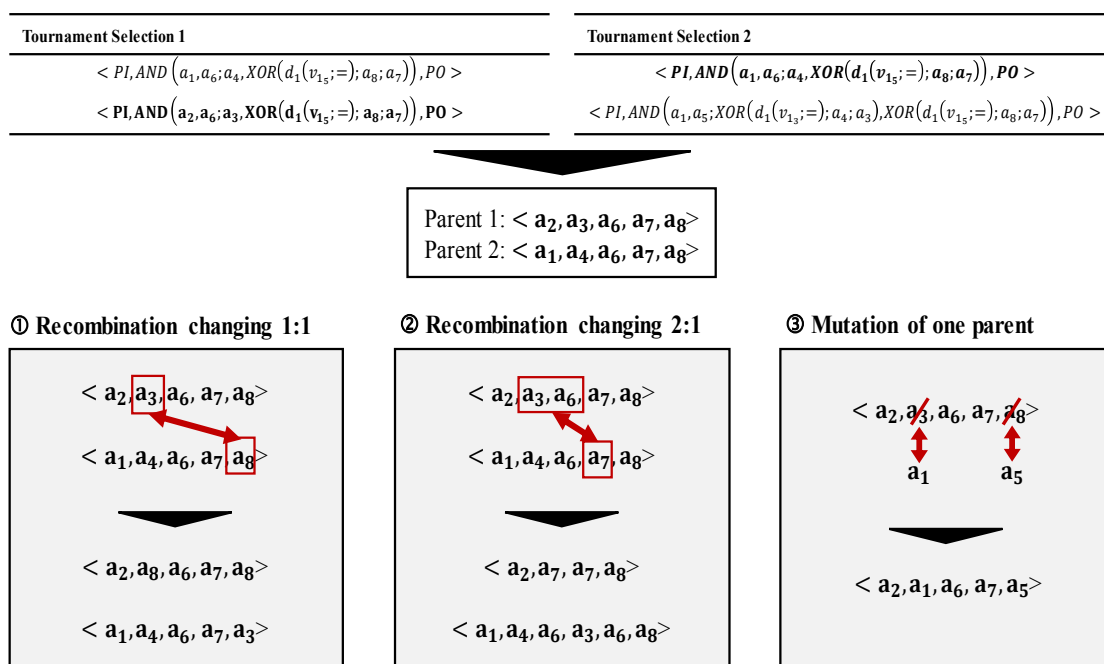


Figure 6. Recombination and mutation examples

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 7* summarizes our results and the input parameters presented in this section.

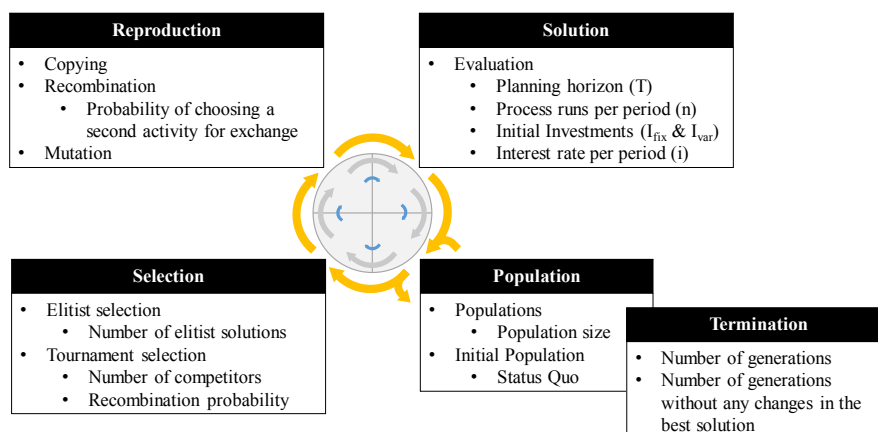


Figure 7. Input parameter for EA application

IV.2.6 Evaluation

IV.2.6.1 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 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).

Design Objectives	Characteristics of our CI applications
Summary	<i>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.</i>
(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) 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.
(O.3) 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.

Table 9. Results of feature comparison

IV.2.6.2 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 as it already provides basic input/output and analysis functionalities. We implemented the computational logic using VBA 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 EA notation.

Using the prototype requires several steps. First, activities, objects, 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 *object-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 8*) only lists performance information and highlights the best designs, the evaluation sheet (*Figure 9*) graphically presents the development of the fitness value over generations and provides further statistics about the simulated designs as well as the included activities.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1			back											
8		Start	No. of Activities			Objective value			E[CF]			σ (E[CF])		
9	Run	Generat	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min
100	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
101	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
102	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
103	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
104	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
105	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
106	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
107	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
108	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
109	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

Figure 8. EA summary spreadsheet

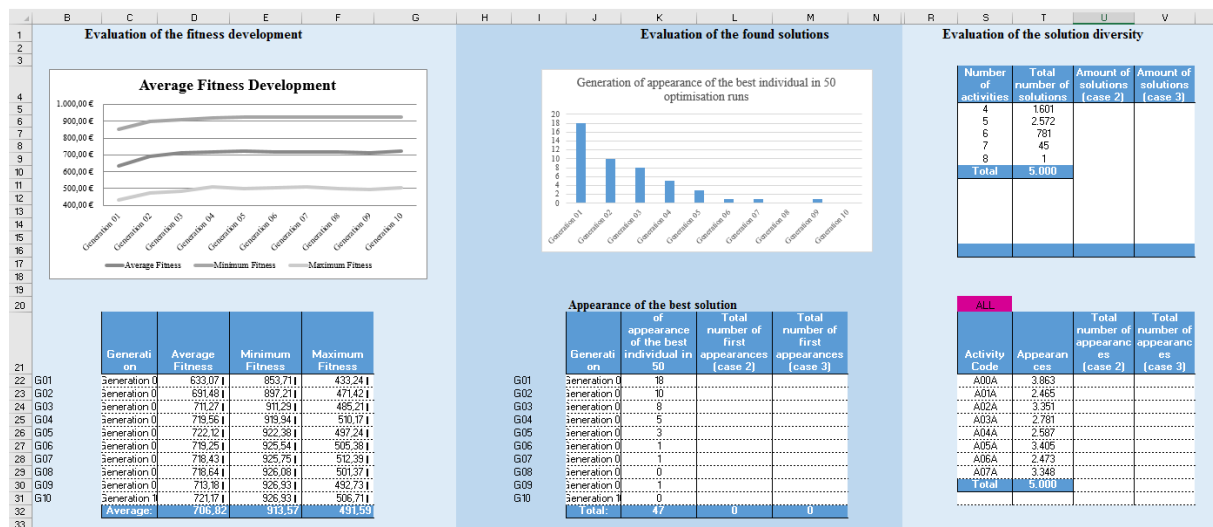


Figure 9. Evaluation spreadsheet

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.

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. In doing so, we used a different representation of in-/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 objects 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., $\langle PI, AND(a_1, a_6; a_3, XOR(d_1(v_{15}; =); a_8; a_7)) \rangle$, 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 10*. 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 objects and 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.

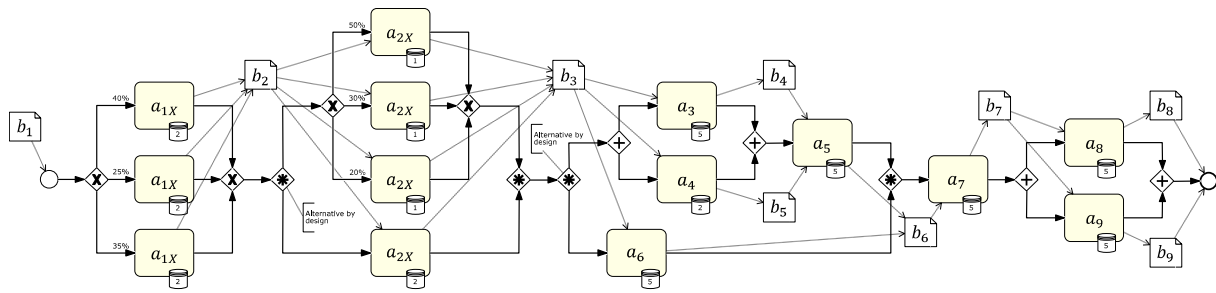


Figure 10. Schematic representation of scenario B

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 11 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.

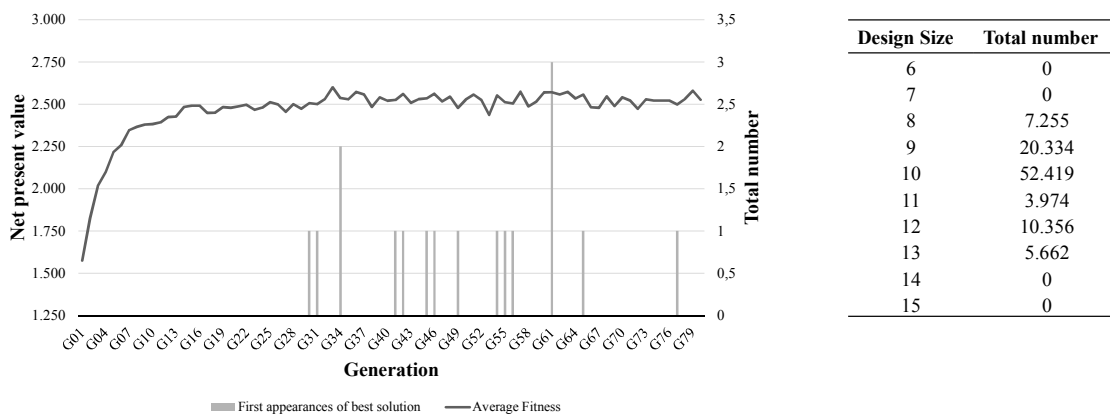


Figure 11. Results of scenario B

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 6.

Criterion	Characteristics of the CI application and the software prototype
Feasibility	The prototypical implementation and the artificial cases (scenarios A and B) 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. Generalizing the results from our two scenarios, we can state that the EA is basically applicable to all classes of processes, but it best fits mature processes. The EA operates on diverse matrices as atomic representation of design opportunities. Accordingly, organizations need fine-grained process knowledge to apply the EA. For immature processes or young organizations, such a deep process experience could not yet have been made and filling out the process matrices is more like a blind guess. For this class of process, the unstructured redesign method as described by Limam Mansar et. (2009) promises better results as human intuition and brainstorming methods are exploited to identify new process designs.
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, objects, 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, objects, 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. However, simulation performance dropped from scenario A to scenario B indicating weaknesses towards the prototype's scalability.
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 objects 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.

Table 10. Discussion of usefulness

IV.2.7 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, objects, 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 maintaining 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 Sonnenberg and vom Brocke's (2012) framework. In this paper, we reported on the results of feature comparison, prototype construction, and demonstration examples to fulfil 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. Thereby, it could be developed to a scalable, platform- and vendor-independent application with well-defined interfaces for data in-/output that connect to existing BPM systems. From a conceptual

perspective, the growing interdependencies of processes in today's 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), complexity will increase owing to this broader interpretation imposing run time and performance problems, which should also be addressed. 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 be 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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V Normative Guidance on Operational Redesign Decisions

V.1 An Economic Decision Model for Determining the Appropriate Level of Business Process Standardization¹

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Abstract

Business process management (BPM) is an acknowledged source of corporate performance. A well-established element of the BPM toolbox by which organizations intend to improve process performance is business process standardization (BPS). So far, research on BPS has predominantly taken a descriptive perspective, analyzing how BPS affects different dimensions of process performance (e.g., cost, quality, time, flexibility). Only very few studies capitalize on the mature body of descriptive BPS knowledge to determine an appropriate BPS level for an organization's processes. Moreover, these studies do not resolve the BPS trade-off, i.e., the partly conflicting effects of BPS on process performance. To address this research problem, we propose a decision model that provides guidance on how to determine an economically appropriate BPS level for a business process. We thereby adopt the design science research (DSR) paradigm and draw from the body of knowledge on BPS as well as value-based management. We evaluated the decision model by discussing its design specification against theory-backed design objectives. We also validated the model's applicability and usefulness in a real-world case where we applied the decision model and a prototypical implementation to the coverage switching processes of an insurance broker pool company. Finally, we challenged the decision model against accepted evaluation criteria from the DSR literature.

¹ Improved Version

V.1.1 Introduction

Business process standardization (BPS), a well-established element of the business process management (BPM) toolbox, is driven by the ongoing pressure to improve process performance (Münstermann et al. 2010; Ramakumar and Cooper 2004). In an example of the large potential of BPS, IBM is reported to have saved more than \$9 billion and increased both the quality and on-time delivery rates of its processes by 75 % (Hammer and Stanton 1999). Such success stories are leading an increasing number of organizations to consider standardizing their processes, driving the need for well-founded guidance on BPS decisions (Ludwig et al. 2011; Manrodt and Vitasek 2004; Rosenkranz et al. 2010). This industry need is consistent with the scholarly perspective that considers BPS an important yet under-researched topic (Münstermann and Weitzel 2008; Urgan 2006; Venkatesh 2006; von Stetten et al. 2008).

Providing guidance on BPS decisions requires that the fundamental BPS trade-off be addressed (Manrodt and Vitasek 2004). The BPS trade-off results from the interplay of two conflicting effects: On the one hand, BPS positively influences different dimensions of process performance, such as time, cost, and quality (Münstermann et al. 2010). On the other, BPS causes investments and may reduce an organization's ability to meet customer needs (De Vries et al. 2006; Hammer and Stanton 1999). While BPS has been intensely studied from an information systems (IS), operations management, organizational design, and BPM perspective, the BPS trade-off has yet to be fully analyzed (Münstermann and Weitzel 2008; Venkatesh and Bala 2012). There is a mature body of descriptive knowledge on how BPS affects different dimensions of process performance and on the partially conflicting nature of these BPS effects (Münstermann et al. 2010; Rosenkranz et al. 2010; Schäfermeyer et al. 2010). However, only very few studies leverage this body of descriptive knowledge in order to support organizations in determining an appropriate BPS level for their processes (Münstermann and Weitzel 2008; Romero et al. 2015).

From an operations management perspective, Lee and Tang (1997), for instance, proposed a decision model for valuating BPS by standardizing production processes until an output-specific treatment is unavoidable. Thereby, BPS creates value as it decreases the inventory buffers between process steps and enables organizations to balance demand uncertainties. Building on Lee and Tang (1997), the operations literature further analyzes the benefits that result from this postponement strategy. Aviv and Federguen (2001) specify the effects introduced by Lee and Tang (1997) for unknown demand distributions and correlations. Ma

et al. (2002) analyze the postponement strategy in the context of a multi-stage assembly system, highlighting the role of lead-time dynamics for the value of standardization benefits. Nevertheless, the postponement strategy neglects essential parts of the BPS trade-off, such as improvements in quality and the reduced ability to meet customer needs. As another example, Letmathe et al. (2013) exploit a similar idea more generally by analyzing the economic effects that result from demand-related, intra-process, and inter-process correlations on combined sales and manufacturing systems. Transferred to the BPS context, one can argue that BPS increases inter-process correlations and reduces diversification effects from higher process variation. From an IS/BPM perspective, Hammer and Stanton (1999) provide a rule of thumb for determining the optimal level of BPS, advising organizations to standardize their processes as far as possible without interfering with their ability to meet customer needs. They thus recommend standardizing a process up to the point where the BPS trade-off begins. Zellner and Laumann (2013), in contrast, integrate several BPS effects into a multi-dimensional decision model. However, they treat all BPS effects as equally strong, neglect relevant process characteristics, and abstract from the partially conflicting nature of the BPS effects. Summing up, despite the mature body of descriptive knowledge on BPS, there is a lack of prescriptive knowledge on how organizations can determine to what level they should standardize their processes, considering the partially conflicting effects of BPS on process performance. Therefore, we investigate the following research question: *How can organizations determine the appropriate BPS level for their business processes, considering the effects of BPS on process performance?*

To address this research problem, we developed a decision model that helps organizations determine the economically appropriate BPS level of a distinct business process. Like in every decision model, we had to make assumptions to transfer the real-world problem of BPS into a solvable, artificial representation. As we require deep knowledge of the users' process behavior for parameterization, our decision model best fits mature processes that operate in a stable environment. As thinking about BPS is more relevant for mature organizations that have globally distributed processes and engage in operational excellence, our decision model can serve the most relevant fields of applications. Basically, the decision model is applicable to agile business processes in unstable environments as well. However, the results should be interpreted more consciously, e.g., via additional robustness analyses. When constructing the decision model, we adopted the design science research (DSR) paradigm and drew from the literature on BPS as well as on value-based management

(VBM) as justificatory knowledge (Gregor and Hevner 2013). This study design is sensible for several reasons: First, decision models are valid DSR artefacts (March and Smith 1995). Second, there exists a mature body of descriptive knowledge on how BPS affects process performance, which can be used for prescriptive decision-making purposes (Münstermann et al. 2010; Romero et al. 2015). Third, value orientation is a predominant paradigm of corporate management and, during the last years, has gained importance in process decision-making (Buhl et al. 2011; vom Brocke and Sonnenberg 2015). In process decision-making, value orientation is primarily used to integrate the effects of process decisions on process performance and to resolve conflicts (trade-offs) among these effects if necessary (Bolsinger 2015; Linhart et al. 2015; vom Brocke et al. 2010). By integrating the effects of BPS on process performance in terms of a BPS endeavor's value contribution, value orientation also allows for bridging the strategic and the operational BPS layer (Romero et al. 2015). Finally, due to its focus on maximizing an organization's long-term firm value, value orientation helps address the recommendation to focus on business value-driven BPS decisions (Kauffman and Tsai 2010).

Following the DSR methodology as per Peffers et al. (2008), this study covers the identification of and motivation for the research problem, objectives of a solution, design and development, and evaluation. In Section 2, we outline justificatory knowledge related to BPS and VBM, and derive design objectives (objectives of a solution). In Section 3, we elaborate on the research method and evaluation strategy. In Section 4, we introduce the decision model's design specification (design and development). Section 5 reports on our evaluation activities (evaluation). We conclude in Section 6 by pointing to limitations and future research possibilities.

V.1.2 Theoretical Background and Design Objectives

V.1.2.1 Foundations of Business Process Standardization

To define BPS, we first look at standardization in general. In this, we follow David (1987) who identifies compatibility and interface standardization, minimum quality standardization, and variety reduction standardization by categorizing standardization according to the economic problems it solves. Compatibility and interface standardization introduces technology standards to facilitate communication and ensure product compatibility. The economic phenomenon associated with this type of standardization is network externalities, the theory of which posits that the value of standardization depends on the number of adopters (Gowrisankaran and Stavins 2002). Interface standardization requires information

technology (IT) and process standardization (Venkatesh and Bala 2012). Minimum quality standardization sets reference points for the quality of goods and services to reduce customers' uncertainty. It prevents Akerlof's (1970) markets for lemons where only poor-quality products are traded, which can occur if customers cannot properly evaluate the quality of goods and services. Variety reduction standardization reduces planned or unintentional variation to exploit economies of scale (Swann 2000).

In the literature, BPS is predominantly conceptualized as the unification or homogenization of process variants (Beimborn et al. 2009), acknowledging local variation in processes as inevitable and necessary (Tregear 2015). This conceptualization combines the idea of variety reduction standardization – sometimes interpreted strictly in an all-or-nothing sense – with the definition of processes. For our purposes, processes are structured sets of activities designed to create valuable output (Davenport 1993). They split into business, support, and management processes (Armistead et al. 1999). Business processes create value for external customers, support processes ensure that business processes continue to function, and management processes help plan, monitor, and control other processes (Dumas et al. 2013; Harmon 2010). Table 1 shows selected BPS definitions together with the associated type of standardization.

Definition	Authors	Type
Internal BPS: "Unification (homogenization) of multiple existing business process variants to either one single variant among the existing or to a newly designed target business process, which itself is composed out of selected tasks of the existing business process." (p. 2)	Beimborn et al. (2009), inspired by Münstermann and Weitzel (2008)	Variety reduction standardization
External BPS: "Alignment respectively adaption of unified/homogenized business process variants to an externally available reference business process or an externally available best practice business process." (p. 2)	Beimborn et al. (2009), inspired by Münstermann and Weitzel (2008)	Variety reduction standardization
BPS is the "unification of variants of a given process by aligning the variants against an archetype process. The archetype process can either be created or selected within the focal firm or be based on/adopted from an existing external reference/best in class process." (p. 30)	Münstermann et al. (2010)	Variety reduction standardization
BPS "means the development of a standard or best-practice process to be used as a template for all instances of the process throughout the organization." (p. 422)	Tregear (2015)	Variety reduction standardization
BPS aims to make "process activities transparent and achieves uniformity of the process activities across the value chain and across firm boundaries." (p. 213)	Wüllenweber et al. (2008)	Variety reduction standardization
BPS can "facilitate communications about how the business operates, to enable handoffs across process boundaries in terms of information, and to improve collaboration and develop comparative measures of process performance." (p. 102)	Davenport (2005)	Compatibility and interface standardization
BPS establishes "the best, easiest, and safest way to do an activity." (p. 57)	Sanchez-Rodriguez et al. (2006), inspired by Imai (1997)	Minimum quality standardization

Table 1: Selected BPS definitions from the literature

From an operational perspective, BPS entails the alignment of process variants against a master process, which is also referred to as archetype, standard, or base process

(Münstermann et al. 2010; Reichert et al. 2015; Tregear 2015). The master process can be set equal to an existing process variant, a newly designed target process that comprises selected tasks of existing processes, an external reference process, or an external best practice process (Beimborn et al. 2009). Further strategies for defining a master process are selecting the most frequently used variant, the process variant with the minimum average distance to other variants, and selecting the superset or the intersection of all process variants (Reichert et al. 2015). In the three latter cases, the master process does not need to be a valid process variant that fits distinct process contexts, but may be an artificial process model that serves as foundation for deriving or configuring valid process variants. A process variant is an adjustment in the master process required by the peculiarities of a distinct process context, i.e., the environment or situation in which the variant is executed (Ghattas et al. 2014; Reichert et al. 2015). In practice, process variants are introduced deliberately or emerge from the dynamics of an organization's technological and organizational environment (Beverungen 2014).

In the literature, there is no consensus whether the master process fits all or only a subset of the relevant process contexts. Some authors refer to the unification of process variants against the master process when defining BPS (Münstermann et al. 2010), an argumentation that implicitly makes the case for the master process being applicable to all contexts. Other authors highlight that the master process may not fit all process contexts due to local requirements such as legislative requirements, local market imperatives, or variations in the product/service offering (Reichert et al. 2015; Tregear 2015). This argumentation poses that the master process does not fit all, but at least several process contexts. In fact, aligning process variants against a master process would not make sense if the master process fitted very few process contexts only. We define the master process as a particular process variant that fits more than one and up to all process contexts. Context-specific process variants fit only one process context.

In case an organization adopts an all-or-nothing conceptualization of BPS for a distinct process, it makes the master process mandatory and eliminates context-specific process variants wherever possible, neglecting that process variants usually better fit the peculiarities of the contexts in which the process is executed (Hall and Johnson 2009; Hammer and Stanton 1999). In case an organization conceptualizes BPS from a more balanced variety reduction perspective, it deliberately decides about the appropriate process variant profile, reflecting which process contexts are served by the master process or by a context-specific

variant. The more contexts served by the master process, the higher the level of BPS – and vice versa. Against this background, we formulate the following design objective:

(O.1) *Business process standardization*: To determine the appropriate BPS level for a distinct process, it is necessary to account for process variants and process contexts. Moreover, process variants must be split into context-specific process variants and a standardized master process.

V.1.2.2 Effects of Business Process Standardization on Process Performance

Process performance and the effects of redesign projects can be valued using the Devil's Quadrangle, a multi-dimensional framework that encompasses time, cost, quality, and flexibility (Dumas et al. 2013). With BPS requiring processes to be redesigned when reducing the number of process variants or defining the master process, its effects can be assessed using the dimensions included in the Devil's Quadrangle. The Devil's Quadrangle earned its name from the fact that improving one dimension has a weakening effect on at least one other (Reijers and Liman Mansar 2005). It discloses the conflicts (trade-offs) among performance dimensions that need to be resolved during process redesign. Beyond affecting the performance dimensions included in the Devil's Quadrangle, BPS mitigates outsourcing risk and enhances process governance (Wüllenweber et al. 2008). In line with our focus on the BPS trade-off, we focus on the dimensions of the Devil's Quadrangle. Thus, we specify the following design objective:

(O.2) *Process performance*: To determine the appropriate BPS level for a distinct process, process performance must be conceptualized as a multi-dimensional construct. It is also necessary to account for the partially conflicting effects of BPS on different dimensions of process performance.

Below, we compile those insights from the extant body of descriptive knowledge on BPS that indicate how BPS affects the dimensions of process performance included in the Devil's Quadrangle. This compilation reveals that BPS features positive and negative effects, which together make up the BPS trade-off. BPS positively affects the performance dimensions quality, time, and costs, while negatively influencing flexibility. Table 2 provides an overview (Please note that + indicates improvements and not increases). These effects are similar to that of the redesign pattern "triage". Like BPS, this pattern addresses the balance of standardization and individualization, recommending the integration of two or more alternative tasks into one general task or the division of a general task into two or more alternative tasks, depending on the context (Reijers and Liman Mansar 2005).

Effect	Performance Dimension	Direction	Supporting References
Increased Learning Effect	Cost	+	Henderson (1979)
	Time	+	Jayaram and Vickery (1998)
	Quality	+	Lapr�e et al. (2000); Jayaram and Vickery (1998)
Empirical Evidence	Cost	+	M�nstermann et al. (2010)
	Time	+	M�nstermann et al. (2010); Jayaram et al. (2000)
	Quality	+	M�nstermann et al. (2010); Fredendall et al. (2009)
Decreased Ability to meet customer needs	Flexibility	-	Hall and Johnson (2009); Davenport (2005), Hammer and Stanton (1999)
Elimination of Errors	Cost	+	W�llenweber et al. (2008);
	Quality	+	M�nstermann et al. (2010); Lillrank (2003)
Increased Economies of Scale	Cost	+	S�nchez-Rodr�guez et al. (2006); van Wessel et al. (2006)
Facilitated Communication	Cost	+	Davenport (2005); Ramakumar and Cooper (2004)
Increased Process Understanding	Cost	+	Manrodt and Vitasek (2004); Jayaram and Vickery (1998)
	Time	+	W�llenweber et al. (2008); Lillrank and Liukko (2004);
Improved Documentation	Time	+	Siha and Saad (2008); Urgan (2006)

Table 2: BPS effects on Process Performance

Process Flexibility

An often-discussed issue is the relationship between BPS and process flexibility. Process flexibility is the ability of a process to cope with contextual changes by adapting its structure and behavior in a goal-oriented manner (Wagner et al. 2011). From an operational perspective, process flexibility splits into functional and volume flexibility (Afflerbach et al. 2014). While volume flexibility enables increasing or decreasing the amount of the process output above or below installed capacity (Goyal and Netessine 2011), functional flexibility enables delivering the output variety demanded by the organization's customers (Anupindi et al. 2012). Volume flexibility relates to the establishment of scalable resources for process execution, whereas functional flexibility deals with variety at the process design level. In other words, functional flexibility relates to the creation of process designs, volume flexibility to the designs' execution. Thus, functional flexibility is much closer to BPS as conceptualized from a variety reduction perspective, where process variants and the alignment of variants against a master process play a central role. This difference in closeness to BPS is corroborated by the fact that volume flexibility has been mainly researched from a capacity and a revenue management perspective, whereas functional flexibility has a rich tradition in BPM (Kumar and Narasipuram 2006; Reichert and Weber

2012). Moreover, one of the most popular means for implementing functional process flexibility is flexibility-by-design, a strategy that requires incorporating alternative process variants in a process design at build time and selecting the most appropriate variant at runtime (Schonenberg et al. 2008). This strategy shows the direct relationship between BPS and process flexibility, particularly functional process flexibility. This is why we henceforth focus on functional process flexibility.

Depending on the context, the relationship between BPS and process flexibility can be interpreted as conflicting or complementary (Afflerbach et al. 2014). On the one hand, BPS and flexibility appear to conflict, as BPS reduces the number of process variants and prohibits deviating from variants, whereas more process variants and degrees of freedom during execution help cope with a higher desired output variety (Pentland 2003). On the other, BPS and flexibility appear complementary when, for instance, processes are defined as modules with interfaces that enable assembling processes at runtime to meet the customers' demands (Münstermann et al. 2009). In our case, where BPS is conceptualized from a variety reduction perspective, BPS and process flexibility conflict. If the reduction of process variants leads to a reduced output variety in the sense of output standardization, an organization loses the ability to assign that process variant to a context that fits it best (Ludwig et al. 2011). Instead, an organization must use the master process, which generally fits a distinct process context worse than the related context-specific process variant (Hall and Johnson 2009; Hammer and Stanton 1999). This negative effect on functional flexibility is supported by Davenport (2005) as well as by Hall and Johnson (2009), who identified output standardization as the main reason for BPS failure. They argue that individuality creates value for customers, which may not be available for highly standardized processes. Böhm et al. (2005) share this line of argumentation. In the service domain, where customers are in many cases tightly integrated in an organization's processes, the mere reduction of process variants may be enough to decrease the customers' perceived individuality even if the output itself is not standardized.

Process Costs

BPS reduces the costs of process execution. From a conceptual perspective, the positive effect of BPS on process costs is achieved through the elimination of errors (Wüllenweber et al. 2008), economies of scale (Sánchez-Rodríguez et al. 2006), and facilitated communication (Davenport 2005; Ramakumar and Cooper 2004). BPS fosters process experience and understanding, two effects that yield cost savings (Jayaram and Vickery

1998; Manrodt and Vitasek 2004). Moreover, standardized processes can be supported more easily by IT and, thus, allow for higher levels of automation and economies of scale (van Wessel et al. 2006). Another concept supporting the positive effect of BPS on process costs is the statistical theory of variation (Deming 1994). This theory suggests that process variation causes process outputs to deviate from their target specification and that the elimination of deviations leads to savings. As BPS reduces process variants, standardization implies less variation and lower costs. This relationship has also been validated empirically (Münstermann et al. 2010).

Process Time

The consensus view is that BPS reduces process time, defined as the end-to-end time required to serve a customer or to create one unit of the process output (Münstermann et al. 2010). The positive effect of BPS on process time is supported both conceptually and empirically. First, standardized processes can be performed more easily than non-standardized processes and, thus, require less time (Lillrank and Liukko 2004). By reducing the number of process variants, BPS also enhances process knowledge and transparency, two effects that enable employees working faster (Wüllenweber et al. 2008). Second, BPS increases employees' experience with executing the process tasks and handling material, making it easier to identify sources of delay and parallelization (Jayaram and Vickery 1998). Third, process documentations can significantly reduce process time (Siha and Saad 2008). Combined with the fact that the master process must be documented to be rolled-out, BPS shortens the process time via the documentation of the master process (Ungan 2006). Beyond these conceptual underpinnings, two empirical studies corroborate the positive effect of BPS on process time. In a study of 57 top-tier suppliers to the North American automotive industry, Jayaram et al. (2000) found BPS to be the most influential enabler of time reductions. In addition, Münstermann et al. (2010) found in a cross-industry study that BPS had a significantly positive effect on the duration of human resource processes.

Process Quality

BPS increases process quality, as it helps organizations establish best-practice processes as standards that exhibit higher quality and smaller error probability than do context-specific process variants (Münstermann et al. 2010). As with process costs, variation is a main reason for bad quality (Lillrank 2003). The positive effect of BPS on process quality is also caused by the increased process experience that accompanies BPS (Jayaram and Vickery

1998; Lapré et al. 2000). This relationship has also been confirmed empirically, e.g., in the health care industries (Fredendall et al. 2009; Münstermann et al. 2010).

V.1.2.3 Value-based Management

The analysis of how BPS affects the performance dimensions of the Devil's Quadrangle revealed that the BPS trade-off has positive effects on process quality, time, and costs as well as negative effects on process flexibility. With the Devil's Quadrangle only proposing a heuristic means to deal with trade-offs (Reijers and Liman Mansar 2005), we adopt value-based BPM to resolve the BPS trade-off (Buhl et al. 2011). Thereby, value-based BPM applies the principles of VBM to process decision-making.

In economic research and practice, VBM has prevailed as the guiding paradigm of corporate management (Buhl et al. 2011). VBM aims at sustainably increasing an organization's firm value from a long-term perspective (Ittner and Larcker 2001; Koller et al. 2010). It extends the shareholder value approach that goes back to Rappaport (1986) and was advanced by Copeland et al. (1994) as well as by Stewart and Stern (1991). Due to its long-term perspective, VBM also complies with the more general stakeholder value approach (Danielson et al. 2008). For VBM to be fully realized, all corporate activities on all hierarchy levels must be aligned with the objective of maximizing the firm value. To do so, organizations must not only be able to quantify the firm value on the aggregate level, but also the value contribution of individual assets and decisions considering their cash flow effects, the time value of money, and the decision-makers' risk attitude (Buhl et al. 2011). In line with investment and decision theory, the valuation functions that are typically used for determining an organization's firm value or the value contribution of individual assets or decisions depend on the decision situation and the decision-makers' risk attitude (Buhl et al. 2011; Damodaran 2012). In case of certainty, decisions can be made based on the net present value (NPV) of future cash flows using a risk-free interest rate for discounting. Under risk and for risk-neutral decision-makers, decisions can be made based on the expected NPV again using the risk-free interest rate. In case of risk-averse decision-makers, alternatives can be valued via their risk-adjusted expected NPV, which may among others be calculated via the certainty equivalent method or a risk-adjusted interest rate (Copeland et al. 2005).

In the last years, VBM in general and the related valuation functions in particular have become increasingly central to process decision-making (vom Brocke and Sonnenberg 2015). Value-based BPM aims at increasing an organization's long-term firm value by

making process- and BPM-related decisions based on their value contribution (Buhl et al. 2011). As value-based BPM inherits VBM's long-term orientation, it also accounts for non-monetary value dimensions such as ecological and social responsibilities, which are important to BPM, but hard to quantify (vom Brocke et al. 2011). Ever more approaches adopt the principles of VBM to support process and BPM decisions in an economically well-founded manner (Bolsinger et al. 2015). Operating on the control flow level, some approaches help compare alternative process designs and/or propose recommendations for improvement (Bolsinger 2015; vom Brocke et al. 2010). Other approaches focus on process performance and process characteristics that capture how work is organized and structured (Afflerbach et al. 2014; Linhart et al. 2015). Still very few approaches analyze BPM-related decisions such as the development of an organization's BPM capability from a VBM perspective (Lehnert et al. 2014).

In the literature, numerous paradigms are related to value-based BPM. The most prominent examples are goal-oriented BPM (Neiger and Churilov 2004a), value-focused BPM (Neiger and Churilov 2004b; Rotaru et al. 2011), value-driven BPM (Franz et al. 2011), and value-oriented BPM (vom Brocke et al. 2010). For more details on these paradigms, please refer to Bolsinger (2015). Value-based BPM draws on the functions introduced above for comparing decision alternatives (Bolsinger 2015). In line with our intention to determine the economically appropriate BPS level for a distinct process, a problem that requires comparing many process variant profiles, we adopt value-based BPM. Thus, we define the following design objective:

(O.3) *Value-based management*: To determine the appropriate BPS level for a distinct process, it is required to cater for cash flow effects and the time value of money. Moreover, the involved decision-makers' risk attitude must be considered.

V.1.3 Research Method and Evaluation Strategy

In the design and development phase of DSR, we combined normative analytical modeling and multi-criteria decision analysis as research methods to develop the decision model for determining the economically appropriate BPS level of a distinct business process. Normative analytical modeling captures the essentials of a decision problem in terms of closed-form mathematical representations to produce a prescriptive result (Meredith et al. 1989). Multi-criteria decision analysis assists with structuring decision problems, incorporating multiple criteria, resolving conflicts (trade-offs) among criteria, and appraising value judgments to support a deliberate choice among decision alternatives (Keeney and

Raiffa 1993). Thereby, relevant decision criteria must be quantified, decision variables and constraints must be defined, and non-trivial assumptions must be made transparent (Cohon 2004). The result of applying normative analytical modeling and multi-criteria decision analysis is formulated in terms of a decision model including decision variables and alternatives, constraints as well as assumptions. Combining both research methods is reasonable as determining the economically appropriate BPS level requires valuing and comparing multiple process variant profiles. Addressing the BPS trade-off also requires conceptualizing performance as a multi-dimensional construct and resolving conflicts among performance dimensions. Finally, determining an appropriate BPS level is such complex that decision alternatives, i.e., process variant profiles, can neither be valued nor compared manually. Thus, a mathematical design specification serves as direct input for implementing a software prototype.

When developing the decision model, we followed Cohon's (2004) recommendations: We first introduce the decision model's general setting and define the underlying demand model (Sections 4.1 and 4.2). We then model the effects of BPS on each performance dimension separately, while highlighting relevant assumptions (Sections 4.3 to 4.5). This complies with the literature that requires proposing mathematical functions for each decision criterion. Finally, we present the decision model's objective function for determining the value contribution of process variant profiles (Section 4.6). This objective function operationalizes the valuation functions used in VBM and integrates the so far isolated effects of BPS on individual performance dimensions. Complying with the principles of VBM, the objective function accounts for the cash flow effects of a BPS endeavor, the time value of money, and the involved decision-makers' risk attitude.

To demonstrate and evaluate the decision model, we followed Sonnenberg and vom Brocke's (2012) framework of evaluation activities in DSR. This framework combines ex-ante/ex-post and artificial/naturalistic evaluation (Pries-Heje et al. 2008; Venable et al. 2012). Ex-ante evaluation is conducted before, ex-post evaluation after an artefact's instantiation, e.g., a prototypical implementation. Naturalistic evaluation requires artefacts to be challenged in the real world by people, tasks, or systems. Making the case for a progressive *design-evaluate-construct-evaluate* pattern, Sonnenberg and vom Brocke's (2012) framework comprises four evaluation activities (EVAL1 to EVAL4). EVAL1 aims at justifying the research topic as a meaningful DSR problem. It also requires deriving design objectives from justificatory knowledge to assess whether an artefact helps solve the research problem. We completed this activity in the introduction and the theoretical

background section. Taking an ex-ante perspective, EVAL2 strives for validated design specifications. To validate the decision model's design specification artificially, we discussed it against the design objectives at the end of Section 4, a method called feature comparison (Siau and Rossi 1998). From a naturalistic perspective, we validated the design specification by conducting expert interviews with senior executives (e.g., the Chief Executive Officer and Head of Marketing) from a German insurance broker pool company. This helped us check how organizational stakeholders assess the design specification's understandability and real-world fidelity (Sonnenberg and vom Brocke 2012). EVAL3 is an artificial and ex-post evaluation, striving for validated artefact instantiations. We thus implemented the decision model in Microsoft Excel. We chose Excel as it is widely used for corporate decision-making and its functionality suffices to implement the decision model. Finally, EVAL4 requires validating the instantiation's usefulness and applicability in naturalistic settings. We applied the Excel prototype to the coverage switching processes of the insurance broker pool company, whose executives we interviewed in the naturalistic part of EVAL2. Finally, based on the experience we gained throughout the real-world case, we discuss the decision model's specification and prototypical implementation against accepted evaluation criteria (e.g., effectiveness and efficiency, impact on the artefact environment and user) that were proposed for EVAL4 purposes in the DSR literature (March and Smith 1995).

When presenting the demonstration and evaluation results, we focus on feature comparison to underpin the decision model's contribution to answer the research question (EVAL2) and on the real-world case to assess the decision model's usefulness and applicability (EVAL4). We briefly touch on the results of our naturalistic ex-ante evaluation (EVAL2) when discussing which of the decision model's assumptions hold in the real-world case. When presenting the real-world case, we also focus on the challenges related to data collection. The results of EVAL2 is shown at the end of Section 4, whereas EVAL4 is shown in Section 5.

V.1.4 Design Specification

V.1.4.1 General Setting

The decision model's unit of analysis is an individual, intra-organizational business process. The process is operated in multiple process contexts and aims at creating value for the organization's customers. The organization already decided strategically to standardize the business process in focus. The organization is interested in which contexts should be served

by the standardized master process or a context-specific process variant. Conceptualizing BPS from a variety reduction perspective, the decision model accounts for all possible process variant profiles, where the process variant profiles of complete standardization (i.e., all contexts are served by context-specific process variants) and complete individuality (i.e., all possible contexts are served by the master process) are two extremes out of many decision alternatives. To model the different process variant profiles as our decision alternatives, we use multiple variables $x_c \in \{0; 1\}$, indicating whether a process context c is covered by the respective variant ($x_c = 1$) or the master process ($x_c = 0$). We further differentiate between process variant profiles prior to BPS (x_c) and after BPS (x_c^{std}). With the decision model adopting the principles of VBM, we make the following assumption as a foundation for specifying the decision model's objective function:

(A1) *The organization adopts the principles of VBM. It judges process variant profiles according to their value contribution, measured in terms of the risk-adjusted expected NPV of the process cash flows.*

Below, we first introduce the demand model underlying the decision model. After that, we model the effects of BPS on each dimension of the Devil's Quadrangle separately and then integrate these effects into the decision model's objective function, i.e., the risk-adjusted expected NPV of the process cash flows. An overview of all mathematical variables used in the decision model's design specification can be found in Appendix F.

V.1.4.2 Demand Model

As the process variant profile determines how the process demand is allocated to the master process and the context-specific process variants, we first model the periodic process demand. We assume:

(A2) *The periodic process demand D_t follows a constant trend μ_D , where random deviations Z_t from that trend occur in each period. The periodic deviations are normally distributed with an expected value of 0 and a standard deviation σ . The periodic deviations are independent from one another.*

Using a normally distributed demand with a constant trend is a widely adopted approach in economic (BPM) research (Buhl et al. 2011; Ryan 2004). The constant trend captures relative changes in the periodic process demand over time and allows for dealing with different planning horizons and economic situations. The normally distributed deviations represent the demand risk in terms of an unsystematic noise around the trend. The periodic

process demand can be modeled based on the initial process demand D_0 , the constant trend, and the deviations as shown in Equation (1).

$$D_t = D_0(1 + \mu_D)^t + \sigma Z_t \text{ with } Z_t \sim N(0,1) \quad (\text{Eq. 1})$$

V.1.4.3 Process Flexibility

As argued in the literature, the main downside of BPS is that an accompanying output standardization may reduce the process' functional flexibility. That is, the process may no longer be able to fully meet the output variety demanded by the organization's customers (Hall and Johnson 2009). As process variants better fit the peculiarities of the process contexts than the master process, BPS may reduce the demand for those process contexts served by the master process (Hammer and Stanton 1999). Thus, we make the following assumption:

(A3) *The periodic process demand is allocated to process contexts according to constant demand weights $w_c \in [0; 1]$, where $\sum_{c=1}^n w_c = 1$ and n is the number of process contexts.*

Prior to BPS, each process context has a specific periodic demand $D_{c,t} = w_c D_t$. A distinct fraction of this demand $f_c \in [0; 1]$ can only be tapped if the context is served by the related context-specific process variant. If, according to a distinct process variant profile, a process context is served by the respective process variant prior to BPS and the master process after BPS, its periodic demand relatively decreases by f_c to $D_{t,c}^{\text{std}} = (1 - f_c)w_c D_t$. Contrariwise, the periodic demand of the respective process context relatively increases by $f_c/(1 - f_c)$ to $D_{t,c}^{\text{std}} = (1 + f_c/(1 - f_c))w_c D_t = (1 - f_c)^{-1}w_c D_t$.

Based on the decision variables x_c and x_c^{std} , we can derive the periodic demand $D_{t,v}^{\text{std}}$ for distinct process variants v and the periodic demand $D_{t,0}^{\text{std}}$ that accumulates on the master process. We use the variant index $v = 0$ to refer to the master process and $v > 0$ to refer to context-specific process variants. The demand of a process context is allocated to the respective process variant if the process variant is offered after BPS ($x_c^{\text{std}} = 1$). The demand for all process contexts not served by the respective process variants after BPS is accumulated on the master process ($x_c^{\text{std}} = 0$). Equation (2) models the periodic demand and allocation effects of BPS via a power function that uses the difference between the decision variables before and after BPS as exponent.

$$D_{t,v}^{\text{std}} = x_c^{\text{std}} D_{t,c}^{\text{std}} = x_c^{\text{std}} \left[(1 - f_c)^{(x_c - x_c^{\text{std}})} \right] w_c D_t \text{ (with } c = v \text{ and } 1 \leq c, v \leq n) \quad (\text{Eq. 2})$$

(for the process variants)

$$D_{t,0}^{\text{std}} = \sum_{c=1}^n (1 - x_c^{\text{std}}) D_{t,c}^{\text{std}} = \sum_{c=1}^n (1 - x_c^{\text{std}}) [(1 - f_c)^{(x_c - x_c^{\text{std}})}] w_c D_t$$

(for the master process)

The total periodic process demand after BPS D_t^{std} is determined by summing up the context-specific demands, as shown in Equation (3). The demand factor δ represents the total relative change in the process demand due to BPS. The BPS-adjusted demand weights $w_v^{\text{std}} \in [0; 1]$ for a variant v are derived as the relation between the variant-specific periodic demand and the total periodic process demand, as shown in Equation (4).

$$D_t^{\text{std}} = \left(\sum_{c=1}^n (1 - f_c)^{(x_c - x_c^{\text{std}})} \right) w_c D_t = \delta D_t \text{ with } \delta := \sum_{c=1}^n (1 - f_c)^{(x_c - x_c^{\text{std}})} w_c \quad (\text{Eq. 3})$$

$$w_v^{\text{std}} = \frac{D_{t,v}^{\text{std}}}{D_t^{\text{std}}} \text{ (for the process variants)} \quad (\text{Eq. 4})$$

$$w_0^{\text{std}} = \frac{D_{t,0}^{\text{std}}}{D_t^{\text{std}}} \text{ (for the master process)}$$

V.1.4.4 Process Costs

We now integrate the positive effects of BPS on process costs (Münstermann et al. 2010). The experience curve, a widely accepted concept for modeling cost developments over time, assumes that the costs of creating an output unit decrease by a constant percentage each time the cumulated output doubles (Henderson 1979). The relationship between costs and cumulated output is often expressed by the power law function shown in Equation (5).

$$C(D_{\text{cum}}, a) = K D_{\text{cum}}^{-a} \quad (\text{Eq. 5})$$

Equation (5) calculates the costs of the next output unit if a distinct cumulated output or, in the absence of capacity restrictions, a cumulated demand D_{cum} has been reached. The process costs depend on the costs K for the first output unit, the cumulated demand as a measure for experience, and the elasticity of the process costs $a \in \mathbb{R}^+$ regarding the cumulated demand. As it is accepted that process cost elasticity is constant within industries, it can also be treated as constant across process variants (Henderson 1979). For repetitive processes in a steady state, the experience curve can be linearly approximated by its tangent at the flat end of the power function (Appendix A.1). Such a linear approximation implies almost no approximation errors. If the cumulated demand becomes large as it is the case for mature processes, the approximation error converges towards zero. For instance, if we

assume a 90% experience curve ($a = 0.9$), a cumulated demand up to the decision time of 1,000,000 units and a periodic demand of 1,000 units, the relative approximation error is $8.54 \cdot 10^{-7}$ for the first time period and $8.46 \cdot 10^{-5}$ for the tenth period. Using such a linear approximation also fits our function for the periodic process demand from Equation (1), as normal distributions are invariant against linear transformation. Using a linear approximation leads to the process costs function shown in Equation (6).

$$C(D_{t,\text{cum}}^{\text{std}}, a) = C_0 - C_0 \tilde{a} D_{t,\text{cum}}^{\text{std}} \text{ for } \tilde{a} = \frac{a}{D_{0,\text{cum}}} \quad (\text{Eq. 6})$$

In Equation (6), the process costs C depend on the process costs at the decision point C_0 , on the cost reductions—which in turn depend on the elasticity of the process costs a adjusted by the cumulated demand $D_{0,\text{cum}}$ up to the decision point—and on the cumulated demand $D_{t,\text{cum}}^{\text{std}}$ that has been reached starting from the decision point. To justify the application of the linear approximation in our decision model, we assume:

(A4) *The linear relationship between the cumulated demand and the process costs is constant across all process variants. The process costs remain constant within one period.*

Based on the process costs, we can derive the periodic profit margin M_t , as shown in Equation (7) (Appendix A.2). We therefore determine the variant-specific periodic process costs by inserting the cumulated variant-specific demand into the linearly approximated experience curve from Equation (6), including the master process as a particular variant. Subtracting this intermediate result from the sales price of the process output leads to the variant-specific periodic profit margins $M_{v,t}$. Profit margins also depend on their value at the decision point $M_{v,0}$ and increase linearly based on the adjusted elasticity of the process costs \tilde{a} . To calculate the total periodic profit margin, the variant-specific profit margins are aggregated based on the demand weights after BPS from Equation (4). On this aggregated level, the total periodic profit margin can still be divided into profit margin M_0 at the decision point and the periodic increases resulting from experience curve effects.

$$M_t = M_0 + \tilde{a} D_{t,\text{cum}}^{\text{std}} G_{\text{cost}} \quad (\text{Eq. 7})$$

As can be seen from Equation (7), increases in the periodic profit margin depend not only on the cumulated demand that has been reached starting from the decision point and the elasticity of the process costs. They also depend on the cost-weighted Gini coefficient G_{cost} of the demand weights after BPS that result from a distinct process variant profile. In general, the Gini coefficient equals the sum of the squared frequencies or probabilities of a

distribution and captures the concentration of a distribution (Gini 1921). In our case, the Gini coefficient $G \in [0; 1]$ equals the sum of the squared variant-specific demand weights after BPS, as shown in Equation (8). The cost-weighted Gini coefficient, as shown in Equation (9), also considers variant-specific costs.

$$G^{\text{std}} := \sum_{v=0}^n (w_v^{\text{std}})^2 \quad (\text{Eq. 8})$$

$$G_{\text{cost}} := \sum_{v=0}^n (w_v^{\text{std}})^2 C_{v,0} \quad (\text{Eq. 9})$$

In our case, the Gini coefficient measures the concentration of the periodic process demand on process variants and the master process resulting from a process variant profile. The Gini coefficient therefore directly depends on the assignment of process contexts to the master process and context-specific process variants. The more process contexts are served by the master process, the more demand concentrates on it. For complete standardization, the process demand concentrates on the master process entirely, and the corresponding Gini coefficient is $G = 1$ (if the master process fits all relevant process contexts). The more process demand concentrates on the master process, the stronger are the experience curve effects and, consequently, the more the process costs lower over time. Using the Gini coefficient is appealing because BPS can be easily measured as the concentration of the process demand on the master process. Moreover, each process variant profile leads to a distinct value of the (cost-weighted) Gini coefficient.

V.1.4.5 Process Time and Process Quality

We integrate the positive effects of BPS on process time and quality in four steps. We first model the direct positive effects of BPS on time and quality. Second, we associate these quality and time effects with increased customer satisfaction (Anderson 1994). Third, we derive a positive effect of customer satisfaction on the retention rate, defined as the proportion of customers who buy the process output in the next period as well (Buchanan and Gillies 1990). Fourth, we integrate the retention rate into the constant trend of the process demand from Equation (1). We provide more details on each step below.

In the first step, we model the direct effects of BPS on time and quality. We therefore determine the process variant profile—measured in terms of its Gini coefficient—as well as the corresponding time and quality values for two reference points to set up a linear extrapolation. Analogous to process costs, using the Gini coefficient is a reasonable way of

modeling the BPS effects on time and quality, as BPS also reduces process time and improves quality due to the increased experience (Lapré et al. 2000; Jayaram and Vickery 1998). Building on previous empirical research that identified a linear relationship between BPS and the performance dimensions in focus, we assume (Münstermann et al. 2010):

(A5) *The relationship between the time and quality effects of a process variant profile and the corresponding Gini coefficient is linear.*

The first reference point to serve as input for the linear extrapolation can be determined by using the Gini coefficient G prior to BPS as well as the corresponding quality Q and time T values. For the second reference point, we suggest using the process variant profile of complete standardization because the required values are comparatively easy to estimate. Therefore, we need the quality effect, defined as the relative increase in process quality s_Q , and the time effect, defined as the relative reduction of process time s_T , in case of complete standardization compared to the status prior to BPS. Both effects can be estimated by relying on the quality and time of an internal or external benchmark (e.g., a competitor, another business unit) that already uses standardized processes or by drawing from the results in Münstermann et al. (2010). In case of complete standardization, process quality and time equal $Q \cdot (1 + s_Q)$ and $T \cdot (1 - s_T)$, respectively, and the Gini coefficient equals $G^{\text{std}} = 1$. On this foundation, we can capture the effect of various process variant profiles measured in terms of their Gini coefficient G^{std} , as shown in Equations (10) and (11) (Appendix B.1).

$$Q(G^{\text{std}}) = Q + \frac{Q \cdot s_Q}{1 - G} (G^{\text{std}} - G) = Q + \frac{Q \cdot s_Q}{1 - G} \Delta G \text{ for } \Delta G := (G^{\text{std}} - G) \quad (\text{Eq. 10})$$

$$T(G^{\text{std}}) = T - \frac{T \cdot s_T}{1 - G} \Delta G \quad (\text{Eq. 11})$$

In the second step, we derive the positive effect of process quality and time on customer satisfaction using Anderson's (1994) model for customer satisfaction as a theoretical underpinning. The application of Anderson's (2004) work has two implications: first, process quality and time are integrated into our decision model based on empirically validated research; second, Anderson (1994) provides organizations with guidance on how to adjust his model to their needs. Both implications strengthen the applicability of our model, even if few case-specific data for customer satisfaction are available. Anderson (1994) determined and empirically validated multiple drivers of customer satisfaction SAT , each measured on a 10-point scale. One driver of customer satisfaction is the customers' expectations EXP of certain product characteristics (e.g., quality, time). Closely linked to

the concept of expectations is the theory of confirmation/disconfirmation, according to which customers compare their experience of product characteristics with their expectations of the product (Yi 1990). In case of negative confirmation/disconfirmation *NCD*, the customers' experiences fall short of their expectations and thus negatively affect satisfaction. The opposite holds true for positive confirmation/disconfirmation *PCD*. A third driver of customer satisfaction is quality *Q*. Equation (12) shows Anderson's (1994) linear regression model for customer satisfaction.

$$SAT = \alpha_{SAT} + \beta_Q Q + \beta_{EXP} EXP + \beta_{NCD} NCD + \beta_{PCD} PCD + \varepsilon \quad (\text{Eq. 12})$$

Based on this analysis, we know that each process variant profile leads to relative changes in process quality of $s_Q \Delta G / (1 - G)$, a circumstance directly affecting customer satisfaction in Anderson's (1994) model. We also know that the process time relatively decreases by $s_T \Delta G / (1 - G)$. Assuming that the expectations for time and quality are uniformly distributed within the customer portfolio and considering that time and quality relatively improve by certain percentages, we can state that negative confirmation/disconfirmation relatively decreases and that positive confirmation/disconfirmation relatively increases by the sum of both percentages for a given process variant profile. Process quality affects customer satisfaction twofold—directly, via the respective variable in Anderson's (1994) model, and indirectly, via positive and negative confirmation/disconfirmation. As the literature provides no guidance on whether or how BPS affects customers' expectations, we assume that BPS does not influence customers' expectation, meaning that this factor is constant across all process variant profiles. Therefore, we assume:

- (A6) The expectations for process time and quality are uniformly distributed within the organization's customer portfolio. Moreover, BPS does not influence customers' expectations, as modeled by Anderson (1994).

Given these intermediate results, we can determine how a process variant profile changes customer satisfaction relative to the status quo, as shown in Equation (13) (Appendix B.2).

$$\begin{aligned} \Delta SAT(G^{\text{std}}) = & \beta_Q \left(Q \frac{s_Q}{1 - G} \Delta G \right) + \beta_{NCD} \left(-NCD \frac{s_T + s_Q}{1 - G} \Delta G \right) \\ & + \beta_{PCD} \left(PCD \frac{s_T + s_Q}{1 - G} \Delta G \right) \end{aligned} \quad (\text{Eq. 13})$$

In the third step, we link the changes in customer satisfaction implied by the process variant profiles with the retention rate. To do so, we again refer to Anderson (1994), who also

relates customer satisfaction to the retention rate using a linear regression model. The changes in the retention rate $\Delta r(G^{\text{std}})$ are shown in Equation (14) (Appendix B.3).

$$\Delta r(G^{\text{std}}) = \beta_{SAT} \Delta SAT(G^{\text{std}}) \quad (\text{Eq. 14})$$

In the fourth and last step, we integrate the retention rate into the constant trend of the periodic process demand. The retention rate can be interpreted as an integral part of the demand trend, as it influences how many customers buy the process output in subsequent periods. We therefore conclude that the demand trend μ_D changes by $\Delta r(G^{\text{std}})/10$ for each process variant profile. The changes in the retention rate from Anderson's (1994) model must be adjusted through a division by 10, as shown in Equation (15).

$$\mu_D^{\text{std}} = \mu_D + \frac{\Delta r(G^{\text{std}})}{10} \quad (\text{Eq. 15})$$

V.1.4.6 Objective Function

In line with the principles of VBM, the decision model uses the risk-adjusted expected NPV of the process cash flows caused by a process variant profile as objective function. We derive the objective function starting with the periodic process cash flows CF_t , which equal the product of the periodic process demand D_t and the periodic profit margin M_t , as shown in Equation (16).

$$CF_t^{\text{std}} = M_t D_t^{\text{std}} = M_0 D_t^{\text{std}} + \tilde{\alpha} D_{t,\text{cum}}^{\text{std}} G_{\text{cost}} D_t^{\text{std}} \quad (\text{Eq. 16})$$

The equations for the periodic process demand and the cumulated demand that has been reached starting from the decision point can be simplified using the law of geometric sequences (Appendix C.1). This simplification is justified because the constant trend of our demand model can be translated into a geometric progression—a sequence of numbers where each term after the first is derived by multiplying the previous term with a constant rate. As a result, the summation operator from the cumulated demand can be replaced by a constant growth factor. After the rewritten demand expression is inserted, the periodic process cash flows can be formulated as shown in Equation (17). In the next step, we derive the expected value $E(CF_t)$ of the periodic process cash flows, as shown in Equation (18) (Appendix C.2). Admittedly, rewriting Equations (17) and (19) using the law of geometric sequences makes them look complex, but helps eliminate summation operations such that they can be implemented more easily in a software tool.

$$CF_t^{\text{std}} = \left(\delta D_0 (1 + \mu_D^{\text{std}})^t + \delta \sigma Z_t \right) \left(M_0 + \tilde{\alpha} G_{\text{cost}} \left(\delta \sigma Z_t^{\text{sum}} + \delta D_0 \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} \right) \right) \quad (\text{Eq. 17})$$

$$E(CF_t^{\text{std}}) = \delta D_0 (1 + \mu_D^{\text{std}})^t M_0 + \delta^2 D_0^2 (1 + \mu_D)^t \tilde{\alpha} G_{\text{cost}} \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} + \delta^2 \sigma^2 \tilde{\alpha} G_{\text{cost}} \quad (\text{Eq. 18})$$

To obtain the risk-adjusted expected present value PV as the central part of our objective function, the expected periodic process cash flows from Equation (18) must be discounted using a risk-adjusted interest rate i and cumulated over the planning horizon τ . The same logic holds, when the case of a risk-averse decision-maker is replaced by a risk-neutral decision-maker. In this case, the application of a risk-free interest rate becomes necessary. Again, the risk-adjusted PV can be rewritten using the law of geometric sequences (Appendix C.3). Finally, the risk-adjusted expected NPV of the process cash flows is determined by subtracting the investment outflows that go along with a distinct process variant profile from the risk-adjusted expected PV . Investment outflows occur whenever the process variant profile changes relative to the status quo. Technically, investment outflows have to be considered for a distinct process context if $|x_c - x_c^{\text{std}}|$ equals 1, i.e., either the context-specific process variant is aligned against the master process or vice versa. The overall investment outflows I depend on the cash flows per process variant change I_c as shown in Equation (19).

$$I = \sum_{c=1}^n |x_c - x_c^{\text{std}}| I_c \quad (\text{Eq. 19})$$

Based on the considerations so far, we can formulate the decision model's objective function as shown in Equation (21). According to the objective function, the decision model intends to identify the process variant profile that yields the highest risk-adjusted expected NPV of the process cash flows. The decision model allows for aligning context-specific process variants against the master process as well as for replacing the master process by context-specific variants, as expressed by the decision variables x_c^{std} . The objective function caters for constraints via the constraint set R , which captures restrictions regarding admissible values of x_c^{std} . In line with our definition of the master process, we can thereby express that

the master process is not applicable to distinct process contexts. The entire objective function together with all variables and constraints is shown in Appendix C.4.

$$\text{MAX: } NPV = PV - I \text{ subject to: } x_c^{\text{std}} \in \{0; 1\} \text{ and } R \quad (\text{Eq. 20})$$

To validate whether the decision model's design specification suitably addresses the research question from an ex-ante artificial evaluation perspective, we discuss its characteristics against the design objectives derived from justificatory knowledge. Regarding design objective (O.1), the decision model allows for different process contexts and process variants. It also splits process variants into context-specific process variants and a standardized master process. Whereas context-specific process variants only fit a single context, the master process fits more than one and up to all process contexts. Conceptualizing BPS from a variety reduction perspective, the decision model considers all process variant profiles to determine the optimal BPS level, checking which contexts should be served by the respective specific variants or the standardized master process. As for design objective (O.2), the decision model treats process performance as a multi-dimensional construct. More precisely, it measures process performance in line with the performance dimensions included in the Devil's Quadrangle. The partially conflicting effects of BPS on these dimensions make up the BPS trade-off. The decision model addresses the BPS trade-off by first modeling the effects of BPS on each performance dimensions separately and then integrating the partial models into an overarching objective function. On the one hand, the Gini coefficient as a measure for demand concentration and standardization incorporates learning effects in the dimensions time, quality, and costs. On the other, variant-specific cost and flexibility effects account for the peculiarities on process contexts. The objective function adopts the principles of VBM, reflecting the contribution of different process variant profiles to the organization's long-term firm value. This makes the decision model comply with decision objective (O.3). To sum up, the decision model's design specification addresses all design objectives. We therefore consider the design model as valid from an ex-ante artificial evaluation perspective. Accordingly, the decision model contributes to answering the research question. We revert to the mentioned limitations and ideas for future research in the conclusion.

V.1.5 Validating the Decision Model's Usefulness and Applicability

To show that the decision model is useful and applicable, required data can be gathered, and analyses can be conducted, we present a real-world case where we applied the decision

model and its prototypical implementation to the coverage switching processes of a German insurance broker pool company. For reasons of confidentiality, we must not disclose the case company's identity. We also had to anonymize and slightly modify all data. Below, we first introduce the case company (Section 5.1) as well as the case process together with process variants and the master process (Section 5.2). After that, we illustrate how we collected the required input data (Section 5.3). We then interpret the results of applying the decision model and conduct a robustness analysis where we check the results for sensitivity and where we challenge the master process pre-selected by the case company's management (Section 5.4). In the end, we assess whether the decision model's assumptions hold for the case at hand and challenge the decision model's usefulness as well as applicability by discussing it against accepted evaluation criteria from the DSR literature (Section 5.5).

V.1.5.1 Case Company

The broker pool supports insurance brokers' daily business activities by taking over their back-office processes (e.g., the administration of insurance contracts). Pool members can then focus on their own business processes (e.g., selling insurance contracts, supporting their clients). In return, the pool claims a fraction of the brokers' provisions.

Based on its business model, we can derive the objectives of the broker pool's processes. First, the broker pool must consider insurance brokers as direct customers and the brokers' customers as indirect customers. The broker pool's processes must fit not only the brokers' demands but also those of the brokers' customers. As a result, customer orientation and satisfaction are primary process objectives. Second, the broker pool's success heavily depends on the cost of its processes, making cost efficiency another important objective. Third, the broker pool's processes must be flexible to cope with different broker behaviors, making flexibility another objective. The broker pool thus faces the BPS trade-off.

Our contact points were the broker pool's Chief Executive Officer and the Head of Marketing, who is also in charge of the organization's business processes. The case company's management had already made the strategic decision to standardize the coverage switching process. It was interested whether this decision should apply to all process contexts. From a strategic perspective, the management also decided not to close down the own call center. We considered this strategic decision in terms of an appropriate constraint set, i.e., at least one process context that involves the broker pool's call center must be served by the respective process variant after BPS.

V.1.5.2 Case Process

Before applying the decision model, the case company's management presented the case process and the master process it had already pre-selected. This information enabled us to derive the process variants. The broker pool segments its activities according to insurance and provision types. It distinguishes life and property insurance as well as acquisition and follow-up provisions. The coverage switching process is located within the segment of follow-up provisions from property insurance contracts.

In general, insurance companies transfer provisions directly to the broker pool, which keeps the agreed fraction of the provisions and forwards the remainder to the brokers. To receive follow-up provisions, insurers must acknowledge the broker pool as the end-customers' advisor and transfer their insurance contracts. Otherwise, the customers' contracts must be transferred to another insurance company through new contracts, after which, in contrast to the former insurer, the new insurer must grant follow-up provisions. For reasons of liability and customer satisfaction, new contracts must have the same risk coverage at a better premium than the former contract offered. Below, we analyze the coverage switching process that ensures follow-up provisions (Figure 1).

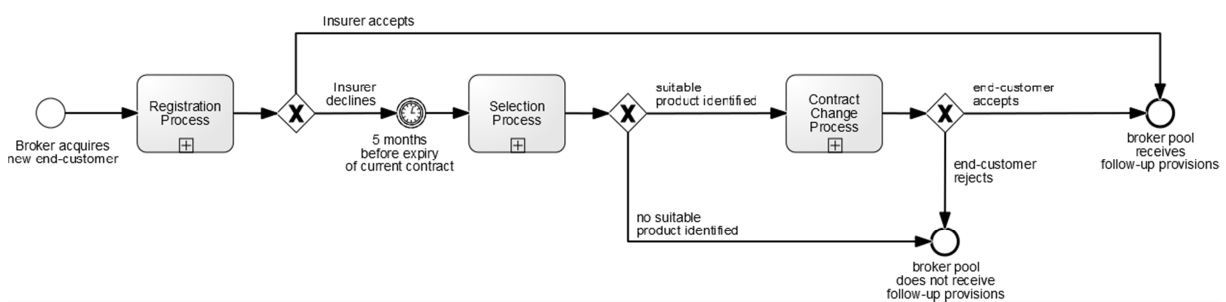


Figure 1: The coverage switching process

Coverage switching processes adhere to the following blueprint. The process starts after an insurance broker, who is a member of the broker pool, acquires a new end-customer. The process consists of three sub-processes: the registration process, the selection process, and the contract change process. In the registration process, the broker pool requests the end-customer's current insurer to transfer the customer's contracts to the broker pool. If the current insurer accepts, the broker pool receives the follow-up provisions, and the end-customer is successfully registered. If the insurer declines, the broker pool analyzes five months before the end-customer's current contract expires whether the customer can be served by a comparable or a standardized product. These activities are performed in the selection process. If a suitable substitute product can be identified, the broker pool buys this

product in consultation with the end-customer within the contract change process, and the broker pool receives the follow-up provisions. If no suitable substitute product can be identified or if the end-customer rejects the new product, the broker pool does not receive follow-up provisions.

In the registration process, the broker submits customer information (e.g., brokerage contract, current insurance policies, billings) in electronic or paper form. In case of electronic submission, the broker pool automatically adds the information to its customer relationship management (CRM) system. If customer information is submitted by paper, the broker pool manually adds the customer information to the CRM system. Next, the end-customer's current insurers are requested to transfer the current insurance contracts (Figure 2).

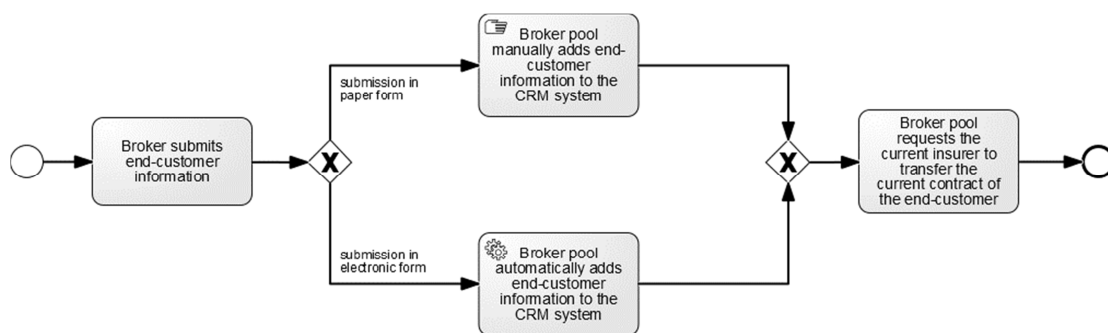


Figure 2: The registration process

In the selection process, the broker pool's selection department analyzes whether the end-customer's current contracts can be transferred to another insurer by concluding new contracts. The selection process is executed separately for each contract, as each insurance type requires specific know-how and IT support. The broker pool has two options for a new insurance product. One option, the suitability of which is checked first, consists in choosing a standardized insurance product. The broker pool establishes strategic partnerships with insurers who agreed to cover the end-customers' risks with standardized insurance products at premiums that are 10% smaller than those of the customers' current contracts. For the standardized product to be suitable, the current contracts must not contain any special conditions, such as the inclusion of e-bike insurance in a household policy. For end-customers whose contracts cannot be transferred to the standardized product, the selection department analyzes the insurance market to identify comparable products with more favorable conditions (Figure 3).

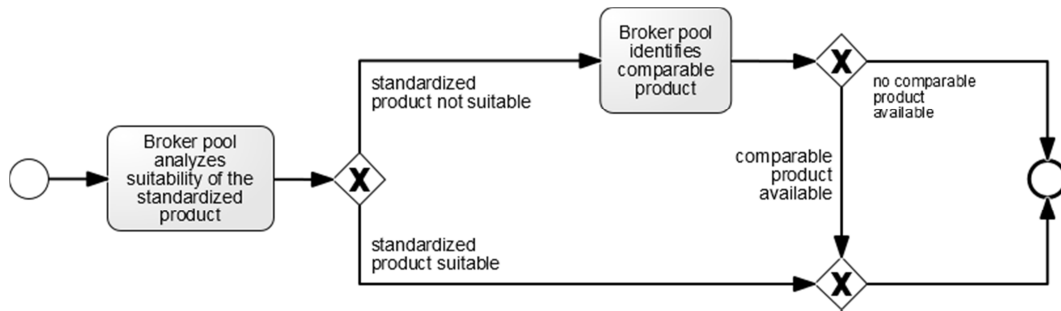


Figure 3: The selection process

In the contract change process, the broker pool renews the end-customer's current insurance contract by buying a comparable or standardized product in consultation with the end-customer. To do so, the broker pool informs the broker that the end-customer's contract can be switched to the new product identified in the selection process. The broker then has three options. The broker can signal a personal contract change, cancel the current contract, and buy the suggested product for the end-customer. If the broker does not want to change the current contract, the broker must update the customer's insurance-specific information (e.g., the customer's residence) in the broker pool's CRM system. If the broker does not react within ten days, the broker pool's call center directly contacts the end-customer to update the information. If the required information is available, the new product is offered to the end-customer. If the end-customer declines the offer, no follow-up provisions are offered. If the end-customer accepts, the broker pool receives the follow-up provisions (Figure 4).

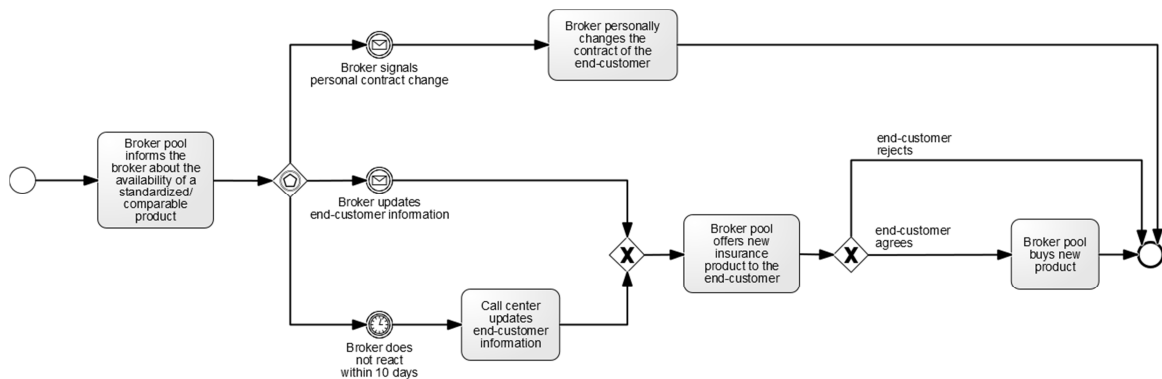


Figure 4: The contract change process

Based on the process models just introduced, we had to specify relevant process variants and the master process. To do so, we used the brokers' preferences to define process contexts. In total, three execution options can be enabled or disabled, which leads to $2^3 = 8$ process variants including the master process. First, brokers can submit end-customer information in either electronic or paper form. Second and third, brokers can decide to update customer information and change the contract themselves or delegate these tasks to the broker pool's call center. Table 4 (left-most column) provides an overview of the process variants

including the master process. The status quo of the case company's coverage switching process is the case of complete individuality, i.e., all execution options were available to the brokers. The master process has already been pre-selected by the case company's management as one of the existing process variants. The management selected the process variant that allows for submitting customer information in electronic form only and where all tasks involving the brokers are assigned to the broker pool's call center. The process model is shown in Appendix D. This is in line with the management's strategic decision of not closing down the call center. We refer to the scenario where this process variant is used as master process as basic scenario. Although the selection of an appropriate master process is outside the decision model's scope, we challenge this decision below as the master process directly affects the optimal level of BPS in terms of the optimal process variant profile (Section 5.4.2).

V.1.5.3 Data Collection

After the presentation of the case process, which was our first encounter with the case company's management, we conducted a semi-structured interview with the Chief Executive Officer and the Head of Marketing in order to collect the input data required for applying the decision model. Both senior executives were interviewed in a single interview by two researchers. One researcher went through the questionnaire and asked follow-up questions, the other researcher took notes. The interview took 2 hours. To enable the interviewees prepare for the interview, we shared the questionnaire in advance. In the same interview, we also collected the data required to challenge the basic scenario by trying two other process variants as master process (Section 5.4.2). The questionnaire and the collected data are summarized in Appendix D. Below, we show the most important data and with their sources for the basic scenario.

Demand Model

We first collected data regarding the process demand. According to our interviewees, the periodic process demand could be reasonably assumed to be normally distributed and independent from one another. The present demand was set at 9,875 executions based on the broker pool's sales information system. The demand trend was estimated at 10% per year, whereas the standard deviation was set at 1,200 executions per year based on historical data from the sales information system.

Execution Options of the Coverage Switching Process

The next important step was determining the demand weights and profit margins for each process variant. Our interviewees estimated that negative demand effects would occur if the execution options for personal contract changes and information updates by the brokers were eliminated. The reason was that the brokers highly appreciated these execution options, often using them to initiate further sales activities (e.g., cross- and up-selling). Eliminating the execution options for personal contract changes and information updates by the brokers would also have negative cost effects due to the higher workload for the broker pool. However, the interviewees also estimated that eliminating these options may increase end-customer satisfaction and internal experience curve effects. The electronic form has positive cost effects on the submission of end-customer information because it avoids the need to register end-customers by hand. Nevertheless, the interviewees estimated that 5% of the brokers would churn if paper submission were no longer possible. The interviewees' estimation on what fraction of the brokers would churn if a distinct execution option were eliminated was based on a broker survey the company conducted when setting up its call center some years before. Information about the cost per execution and the fraction of covered demand was retrieved from the case company's sales information as well as enterprise resource planning system. Table 3 summarizes the information about the execution option.

Execution option	Fraction of the demand covered by this execution option	Costs per execution	What fraction of the currently connected brokers would leave if this execution option were eliminated?
Submission of end-customer information in electronic form	30%	20.00 EUR	5%
Submission of end-customer information in paper form	70%	25.00 EUR	5%
Broker updates information	70%	11.25 EUR	25%
Call center updates information	30%	37.50 EUR	0%
Broker changes contract	80%	3.75 EUR	25%
Call center changes contract	20%	12.50 EUR	0%

Table 3: Information about execution options of the coverage switching process

In order to derive the profit margins and demand weights of the process variants, we assumed, in accordance with the broker pool's management, that the execution options of the coverage switching process are executed independently from one another. We then

calculated the weights of the process variants by multiplying the weights of the respective enabled execution options. We obtained the profit margin of each process variant by subtracting the costs of the enabled execution options from the average revenue per process execution of 90 EUR. The average revenue was retrieved from the company's sales information system. Table 4 shows the demand weights and the profit margins per process variant.

Process Variant	Profit Margin	Demand Weight
Process Variant 0 (Master Process):		
Submission of end-customer information in electronic form	20.00 EUR	0.018
Call center changes contract		
Call center updates information		
Process Variant 1:		
Submission of end-customer information in electronic form	28.75 EUR	0.072
Broker changes contract		
Call center updates information		
Process Variant 2:		
Submission of end-customer information in electronic form	46.25 EUR	0.042
Call center changes contract		
Broker updates information		
Process Variant 3:		
Submission of end-customer information in electronic form	55.00 EUR	0.168
Broker changes contract		
Broker updates information		
Process Variant 4:		
Submission of end-customer information in paper form	15.00 EUR	0.042
Call center changes contract		
Call center updates information		
Process Variant 5:		
Submission of end-customer information in paper form	23.75 EUR	0.168
Broker changes contract		
Call center updates information		
Process Variant 6:		
Submission of end-customer information in paper form	41.25 EUR	0.098
Call center changes contract		
Broker updates information		
Process Variant 7:		
Submission of end-customer information in paper form	50.00 EUR	0.392
Broker changes contract		
Broker updates information		

Table 4: Profit margins and demand weights of the process variants

Experience Curve Effects

As the coverage switching process is highly repetitive with more than 9,000 executions per year, we could legitimately assume the experience curve to be at its flat end. Based on the information from our questionnaire, the execution costs per process instance were reduced by 2.50 EUR to 48.25 EUR (a relative reduction of about 5 %) and the process demand realized on a level of 9,875 executions in the last year. With this information, we could derive the slope of the experience curve through the relationship between the relative cost reduction and the realized process demand: $\tilde{\alpha} = 0.05/9,875 = 5.09 \cdot 10^{-6}$. Our interviewees retrieved this additional information from the company's sales information as well as enterprise resource planning system.

Anderson's Model

To apply Anderson's (1994) model, we gathered the quality in the status quo ($Q = 8$) as well as the time ($s_T = 0.633$) and quality ($s_Q = 0.125$) effects of complete standardization. Our interviewees could estimate these input parameters relatively easily as they planned to use an already running process variant as master process. If they had chosen a novel process variant as the master process, it would have been considerably harder to estimate the quality and time improvements. The derivation of the other parameters from Anderson's model was based on the respective average values for these parameters and the adjustment procedures from Anderson (1994). Appendix D illustrates the adjustment factors, their derivation, and the values obtained from the questionnaire. Knowing the values for the company-specific factors, we calculated the values for positive and negative confirmation/disconfirmation using the following parameterized equations from Anderson (1994):

$$NCD = 1.33 - 1.74 \cdot \frac{1}{20} + 0.25 \cdot 8 - 0.55 \cdot 4 + 0.04 \cdot 3 - 0.08 \cdot 5 + 0.02 \cdot 3 + 0.08 \cdot 9 = 1.54 \quad (\text{Eq. 21})$$

$$PCD = 6.25 - 2.99 \cdot \frac{1}{20} + 0.02 \cdot 8 + 0.03 \cdot 4 + 0.05 \cdot 3 - 0.04 \cdot 5 - 0.07 \cdot 3 - 0.09 \cdot 9 = 5.31 \quad (\text{Eq. 22})$$

The beta-factors for customer satisfaction and the retention rate were derived analogously:

$$\begin{aligned} \beta_{SAT} &= 0.6125 & \beta_{PCD} &= 0.1085 \\ \beta_Q &= 0.501 & \beta_{NCD} &= -0.098 \end{aligned} \quad (\text{Eq. 23})$$

V.1.5.4 Application of the Decision Model

Optimization and Interpretation

In combination with the general planning variables on the planning horizon $\tau = 7$ years and the yearly risk-adjusted interest rate $i = 0.04$, which the company typically uses for

investment decisions according to our interviewees, we derived the values of the objective function for all process variant profiles. To be precise, we only considered process variant profiles that complied with the case company's strategic decision of not closing down the call center. In addition, we omitted possible investment outflows for the elimination of execution options in accordance with the broker pool's management because the costs for employees and IT systems are already included in the process costs. Given the seven process variants and the master process, we had to consider $2^7 = 128$ process variant profiles. We could neglect those process variant profiles where the case company's call center would be shut down. Table 5 shows the values for the objective function and other relevant parameters for the best three process variant profiles as well as for complete standardization as a benchmark. For a more intuitive analysis, we also indicate the delta of the objective functions between a BPS alternative and the status quo. This delta can be viewed as profits or opportunity costs.

Process variant profile	G	μ_D	δ	M_0	Objective function	Delta w.r.t status quo
Standardization of variant 4	0.23	0.10	0.99	42.13 EUR	4,381,438 EUR	21,018 EUR
Complete individuality (status quo)	0.23	0.10	1	41.88 EUR	4,360,420 EUR	0 EUR
Standardization of variants 4 and 1	0.24	0.10	0.98	41.90 EUR	4,308,308 EUR	-52,112 EUR
Complete standardization	1	0.15	0.59	20.00 EUR	2,409,414 EUR	-1,951,006 EUR

Table 5: Results of the optimization (basic scenario)

In our basic scenario, the decision model suggests aligning process variant 4 against the master process (Table 4). The submission of end-customer information for those brokers who personally execute contract changes is then only possible in electronic form. The standardization of process variant 4 increases the risk-adjusted expected NPV of the process cash flows because the positive effects on customer satisfaction and on the cost advantages of the electronic submission exceed the negative effects on the process demand. Relatively to the second-best process variant profile of complete individuality, representing the broker pool's status quo prior to BPS, the objective function increases by about 21,018 EUR. Serving the fourth process context by the master process instead of the respective process variant reduces the context-specific demand by 5% (Table 3, line 2), whereas the demand trend increases only marginally. As a result, the cumulated demand is larger for the status quo than for the standardization of process variant 4. However, the standardization directly increases the average profit margin of this context by 25% (Table 3, lines 1 and 5). The cost advantages even accelerate over time due to experience curve effects. The net effect of the

reduced process demand and the increased profit margin is positive and justifies the elimination of paper-based submission for brokers who personally execute contract changes.

Robustness Analysis

To analyze the robustness of the optimization results, we conducted a sensitivity analysis of the basic scenario. We also challenged the master process, which has been pre-selected by the case company's management, by analyzing two additional scenarios. Each additional scenario uses another existing process variant as master process.

First, to ensure that potential estimation errors do not bias the optimization results of the basic scenario, we determined the optimal process variant profiles for different parameter constellations. We separately varied the values for all parameters except for the profit margins and the discount rate in a range between -50% and +50% of the original estimation in 10% steps, leading to 80 scenarios (Appendix E). Although the values of the objective function change across the scenarios, the expected effects of BPS remain positive. Moreover, the process variant profile, which was determined as optimal for the basic scenario, remained optimal for all other scenarios. We therefore conclude that, in the case at hand, potential estimation errors did not bias the results.

Second, we challenged the pre-selected master process. We can think about using other process variants as master process as there are no regulatory requirements regarding the coverage switching process. As, in our decision model, the parameters demand, time, cost, and quality refer to a specific master process, they must be assessed separately for each master process. In the case at hand, the demand effects could be derived without involving the case company's management from the information about the execution options (Table 3). The cost effects could also be extracted based on the questions that relate to the basic master process, whereas we had to include additional questions to estimate the quality and time effects for the alternative master processes (Appendix D). After discussions with the interviewees, we decided to try process variants 4 and 3 as alternative master processes (Table 4). We did not check for candidates outside the case company as there are no accepted reference models for the coverage switching process. As in the basic scenario, the interviewees could estimate the additional input data easily as both alternative master processes were already existing process variants.

As for process variant 4, the only difference compared to the original master process is that process variant 4 implies a paper-based submission of end-customer information. Using process variant 4 as master process has similar time and quality effects as the original master

process. These effects amount to 90% compared to those of the original master process, because electronic submission process is marginally faster and more reliable than the paper-based submission. In addition, using process variant 4 as master process has cost disadvantages at equal demand effects (Table 3). In this case, the optimal process variant profile is the status quo that reflects *complete individuality*. That is, any standardization against process variant 4 as master process is economically disadvantageous. The reason is that the paper-based submission of end-customer information has disadvantages regarding cost, time, and quality compared to the electronic submission. Thus, using process variant 4 as the master process is not a good idea.

In contrast, process variant 3 differs from the original master process regarding the interaction with end-customers. While the original master process assigns the entire customer contact to the broker pool's call center, process variant 3 assigns all these activities to the brokers. An alignment against process variant 3 would thus require closing down the broker pool's call center. We investigated this case despite the management's strategic decision against closing down the call center because the management was interested in the potential economic consequences (opportunity costs) of this strategic decision. The circumstance that process variant 3 substantially differs from the original master process becomes manifest in the time and quality effects. As a call center-based execution is considerably faster and less error-prone than a broker-based execution, standardization against process variant 3 provides significantly smaller time effects (1.5 times smaller) and quality effects (about half as large) than the standardization against the original master process (Appendix D). In addition, the cost significantly drop such that the profit margin of the process doubles, if the customer contact were outsourced. Moreover, there would be almost no negative demand effects (Table 3). The optimal process variant profile using process variant 3 as the master process is *complete standardization*. The cost advantage is such dominating that it overcompensates for the negative demand, quality, and time effects. The decreases in the demand dynamics are economically less important than the efficiency increases due to the high repetitiveness of the case process. The standardization against process variant 3 also causes a higher risk-adjusted expected NPV than the basic scenario. Whereas the optimal process variant profile in the basic scenario increases the risk-adjusted expected NPV by 21,018 EUR compared to the status quo, complete standardization against process variant 3 leads to an increase of 1,016,108 EUR. From a purely economic perspective, the case company should prefer using process variant 3 as master process instead of the basic scenario. As the case company's management however decided against

closing down the call center, as this would require dismissing 70 employees, it is reasonable to rely on the original master process.

V.1.5.5 Discussion

Validity of the Assumptions

To substantiate the validity of the optimization results, we discussed the decision model's assumptions with the interviewees, particularly with respect to whether the assumptions hold in the case at hand. To do so, we explained the assumptions to the interviewees and asked for their judgement on how far they can be considered fair.

The assumption regarding the principles of VBM (A1) was completely in line with the case company's strategic orientation. For the case company, retaining a strong cash flow position and achieving long-term growth are the two most important strategic objectives. The assumption about the process demand that follows a trend with random deviations (A2) was judged as uncritical. The interviewees confirmed a stably increasing development of the customer base over the past five years. However, they could not exclude disruptive events over the entire planning horizon. A demand model that allows for such exogenous demand shocks would constitute a good extension of the decision model. However, the probability for demand shocks was estimated such low that the implementation of shock events would not dramatically affect the case results. Further, the interviewees considered the assumption regarding constant demand weights (A3) as fair. When deciding about setting up the call center, the company conducted a survey to predict the brokers' behavior. Since the establishment of the call center, the company monitors the call center's utilization to assess its profitability. The results indicate stable usage behaviors as well as a steady distribution over interaction channels. With the coverage switching process counting among the case company's core processes, the interviewees confirmed the assumption about high process maturity (A4). Almost all end-costumers traverse this process. In contrast to the positive feedback regarding assumptions (A1) to (A4), the interviewees criticized the assumptions on the mechanics of quality and time effects (A5, A6). Both the uniformly distributed time and quality tolerances and the linear relationships were judged as not to hold. The sensitivity analysis, however, showed that a violation of these two assumptions does not impact the optimal process variant profile in the case at hand (Section 5.4.2).

Discussion against Evaluation Criteria

As final evaluation step, we discuss the decision model's applicability and usefulness based on criteria that were compiled and assessed by Sonnenberg and vom Brocke (2012) as valid

for evaluation activity EVAL4. In line with the nature of the decision model and its prototypical implementation, we focus on evaluation criteria that relate to the artefact types model and instantiation. The discussion builds on the experience we gained throughout the real-world case. We also collected evaluation-related data in an additional interview with the case company's Chief Executive Officer and Head of Marketing. Wherever reasonable, we generalize beyond the real-world case at hand.

Assessing the *applicability* of our decision model, our real-world case illustrated its performance in naturalistic settings. As the model's calculation logic is complex and the number of process variant profiles grows exponentially with the number of process contexts (see effectiveness and efficiency), the decision model cannot be applied without the prototype. Another issue that affects applicability is that the decision model requires collecting and estimating input data regarding process contexts, process variants, and the master process as well as regarding the effects of BPS on the performance dimensions time, cost, quality, and flexibility. According to our interviews, the case company disposed of most input data and could estimate the rest. Especially the effects of BPS on time and quality were hard to estimate, as the case company's management stated in a feedback interview about potential estimation problems. To cope with estimation inaccuracies, which are inevitable in naturalistic settings, the prototype implements robustness analysis functionality, as discussed in Section 5.4.2. Nevertheless, we recommend building up a knowledge base to institutionalize data collection routines and compile reference data. The interviewees assessed the decision model's ease of use – in the sense of ease of data collection – as appropriate in relation to the decision problem's complexity and relevance. When reasoning about the decision model's applicability, one must also challenge the settings to which the decision model is applicable. We thus take the case-specific reasoning about the decision model's assumptions from Section 5.5.1 to a more general level to highlight industries, process types, and contexts that do not match the decision model. Starting with process types, the decision model is geared to business processes that offer their output to customers, whose demand depends on process quality and time, and for which organizations can in general freely choose which variants they offer. The decision model cannot be applied to support processes where time and quality may not affect process demand, but costs instead. Further, the decision model does not cover immature processes and/or highly dynamic environments. This is for three reasons: learning curve effects are underestimated, customer behavior is unpredictable, and input parameters cannot be estimated reliably. With BPS exploiting learning curve effects, the decision model suggests

higher BPS levels for higher learning curve parameters. It under-standardizes processes if the learning curve effect is underestimated. This is what happens for immature process if learning curve effects are linearly approximated. In dynamic settings, customer behavior is unpredictable, a circumstance that causes the process demand not to be identically distributed across process contexts over the planning horizon. As BPS benefits tend to scale with increasing demand weights, it is crucial that involved decision-makers can reliably estimate how the customer behavior changes in case of standardization. In the case of highly dynamic environments, this may be impossible. Beyond the estimation of demand effects, applying the decision model requires deep insights into the process in order to estimate all input parameters. Such knowledge is not available for newly created processes. Following the same logic, the decision model is less suitable for highly dynamic companies or industries, such as start-ups. Organizations operating in such environments, however, typically follow an explorative strategy and, thus, are not the main stakeholders of BPS. Thinking about BPS is more relevant for mature organizations with globally distributed processes that engage in operational excellence. As for contexts, the decision model does not fit contexts that are highly restricted by regulations or legislation. Aligning respective processes against the master process may imply that relevant restrictions are violated. Further, if many contexts are regulated, it may not be possible to identify a sufficiently applicable master process. As argued for highly dynamic environments, BPS is not the dominant strategy in highly regulated contexts. Consequentially, these contexts are beyond the scope of our decision model, as we aim at providing those organizations with guidance that explicitly assess the potential of BPS. Finally, we conclude that the decision model particularly fits those organizations and business processes that need guidance on BPS.

Concerning, the *impact on the artefact environment and users*, the decision model affected how the case company's management thinks about BPS in general and in particular about how to address the BPS trade-off. On the one hand, the decision model's formal design specification provides insights into the BPS trade-off and into the interplay of central BPS-related constructs such as process contexts, process variants, and the master process. On the other hand, the prototype's robustness analysis functionality helped the case company's management understand the situation and possibilities for action in their organization. Our interviewees also agreed that the decision model enhances their organization's process decision-making capabilities.

In terms of the model's *fidelity with the real-world phenomenon*, we can conclude that our decision model covers relevant constructs (e.g., process variants, process contexts, master

process) as well as performance dimensions, and it can handle different constellations that occur in naturalistic settings. An assessment of the assumptions' validity (Section 5.5.1) underpinned that most assumptions hold in the investigated real-world case. Based on the results of the robustness analysis (Section 5.4.2), we could further show that the violation of two assumptions did not affect the optimization results in the case at hand. So far, we do not have experience to which extent the decision model fits different organizational contexts. This should be subject to future research.

Referring to *consistency*, the decision model is internally consistent as it was designed deductively and as its components are modular such that side effects cannot occur. Further, the decision model's design specification is available in terms of mathematical formulae, a property that facilitates checking internal consistency. As for external consistency, the decision model does not contradict accepted knowledge from other disciplines such as BPM or VBM. Rather, the model builds on knowledge from these disciplines as justificatory knowledge. These disciplines also served as foundation for deriving our design objectives (Section 2).

To evaluate the *effectiveness and efficiency* of our artefact, we analyze the performance of our prototype in our real-world case. When calculating the results of the different scenarios and conducting the robustness analysis, the prototype shaped up as an effective tool. In its current stage of development, the prototype can be applied to academic evaluation settings, not to industry settings. With the decision model checking for each process context whether it should be served by a specific process variant or the standardized master process, the problem complexity grows exponentially with the number of process contexts (2^n). As for efficiency, the prototype uses exhaustive enumeration to determine the optimal process variant profile. Although exhaustive enumeration entails much calculation effort, it is suitable for the decision problem at hand because the number of process variants typically involved is manageable and because BPS decisions need not be made in real-time. We conducted performance tests on regular workstations such as used in business environments. The prototype efficiently processes industry-scale problems, but can only inconveniently be configured for different settings.

V.1.6 Conclusion

V.1.6.1 Summary and Contribution

In this study, we investigated how organizations can determine an appropriate BPS level for their business processes, considering the partially conflicting effects of BPS on process

performance that together define the BPS trade-off. Adopting the DSR paradigm, we developed a decision model that combines descriptive knowledge on BPS with prescriptive knowledge on VBM. The decision model structures the BPS effects on process performance according to the dimensions of the Devil's Quadrangle and resolves conflicts among these dimensions using the contribution of different BPS levels to the organization's firm value as objective function. The decision model formalizes BPS levels via process variant profiles. Process variant profiles indicate whether the contexts in which a process is executed are served by a context-specific process variant or the standardized master process. In general, the decision model entails an optimal BPS level where, throughout a multi-period planning horizon, the demand reduction that results from reduced process flexibility is overcompensated by the higher demand trend that flows from better quality and time. Moreover, for the optimal BPS level, BPS investments are overcompensated by higher profit margins that flow from experience effects. Providing guidance on which process context to serve via a context-specific process variant or the master process, the decision model contributes to the prescriptive body of knowledge on BPS.

When setting up the decision model, the main challenge was to integrate the partially conflicting effects of BPS into a single objective function. The investment outflows associated with a process variant profile as well as the negative BPS effect on process flexibility, i.e., the demand reduction that may result if distinct process contexts are served by the master process, could be directly integrated into the objective function. The positive effects of BPS on process costs were approximated with reference to variant-specific profit margins and the experience curve concept. The positive effects of BPS on process quality and time were integrated into the demand trend by applying the Gini coefficient of the process demand, which measures the demand concentration on the master process, to Anderson's (1994) model of customer satisfaction and retention.

We evaluated the decision model by discussing its design specification against theory-backed design objectives and by prototypically implementing the design specification. Furthermore, we validated the decision model's applicability and usefulness via a real-world case at an insurance broker pool company as well as by discussing the decision model's design specification and the prototype against established evaluation criteria from the DSR literature.

V.1.6.2 Limitations and Future Research

While validating the decision model's design specification, applicability, and usefulness, we identified directions in which the decision model should be advanced. Below, we present these directions together with ideas for future research.

Future research is required with respect to some design objectives. For example, the decision model only caters for the performance effects of the process under investigation. It abstracts from the performance effects coming from interactions with other processes. A more aggregated parameterization of the decision model that account for such effects would constitute a possible extension (O.2). Moreover, the decision model also captures risk and the decision-makers' risk attitude rather implicitly in terms of a risk-adjusted interest rate (O.3). The value contribution's expected value and risk could be modeled more explicitly, e.g., by means of the certainty equivalent method.

Regarding its design specification, the decision model includes simplifying assumptions. The strongest assumption is that about the linear effects of BPS on process quality and time. Although this assumption is backed by empirical findings, reality might be more complex. Moreover, risk and the decision-makers' risk attitude are captured rather implicitly via a risk-adjusted interest rate. They could be addressed more explicitly by modelling the expected value and risk of the decision model's objective function separately, e.g., using the certainty equivalent method. Moreover, the decision model is geared to business processes that offer their output to external customers as well as whose demand depends on process quality and time. Moreover, as for business processes, organizations can in general freely choose which process/output variants they offer their customers. In its current form, the decision model does not fit support processes where time and quality may not affect process demand but costs. To make the decision model fit support processes, low quality can be modeled as additional process executions, and a high time may directly affect costs. For future research, we recommend deliberating which of these limitations should be relaxed. When extending the decision model, one has to keep in mind that models are purposeful abstractions that need not necessarily capture all the complexity of the real world. It is imperative to assess carefully whether an increase in closeness to reality out-values the related increases in complexity and data collection effort.

As for applicability and usefulness, we concede that we applied the decision model once in the context of an insurance broker pool company. While this real-world case corroborated that relevant input data can be gathered and that the decision model provided the involved

decision-makers with useful guidance, we neither have substantial experience in data collection nor about reference data to calibrate the decision model for various application contexts. Future research should thus focus on conducting more real-world case studies in different organizational contexts and on setting up a respective knowledge base. Case studies will not only help gain experience regarding data collection, but also identify how the decision model's design specification must be tailored to fit additional contexts. In order to facilitate additional case studies, we also recommend further developing the prototype such that it can be used more conveniently in naturalistic settings and provides more sophisticated analysis functionality. Finally, future research should develop methods that assist corporate decision-makers in estimating the required input parameters and in determining an appropriate master process. Both topics heavily influence the results of any BPS endeavor, but were beyond this study's scope.

V.1.7 References

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V.1.8 Appendix

A. BPS and Process Margin

A.1 Linear Approximation of the Experience Curve

The process costs C_0 at the decision point can be calculated by inserting the cumulated demand $D_{0,cum}$ up to the decision point into the function of Henderson's Law from Equation (5):

$$C_0 = C(D_{0,cum}, a) = K(D_{0,cum})^{-a} \quad (\text{Eq. A.1.1})$$

We apply the tangent of Equation (A.1.1) to linearly approximate the development of the process costs over the planning horizon. To derive the tangent, we must determine its slope and its tangent point. The slope of the tangent is determined as follows:

$$C'(D_{0,cum}, a) = \frac{\partial C(D_{0,cum}, a)}{\partial D_{0,cum}} = -aK(D_{0,cum})^{-a-1} = -\tilde{a}KD_{0,cum}^{-a} \quad (\text{Eq. A.1.2})$$

$$\text{for } \tilde{a} = \frac{a}{D_{0,cum}}$$

The tangent point equals the costs at the decision point and can be directly observed:

$$C(D_{0,cum}, a) = KD_{0,cum}^{-a} = C_0 \quad (\text{Eq. A.1.3})$$

In the approximated version of Henderson's Law, the process costs linearly decrease in the cumulated demand $D_{t,cum}^{std}$ that has been reached starting from the decision point as shown in Equation (A.1.4)

$$C(D_{t,cum}^{std}, a) = KD_{0,cum}^{-a} - \tilde{a}KD_{0,cum}^{-a} \cdot D_{t,cum}^{std} = C_0 - C_0\tilde{a}D_{t,cum}^{std} \quad (\text{Eq. A.1.4})$$

A.2 Demand-Weighted Process Margin

The profit margin $M_{v,t}$ of a process variant v in period t equals the difference between the sales price P_v and the process costs $C_{v,t}$ in that period, as shown in Equation (A.2.1).

$$M_{v,t} = P_v - C_{v,t} \quad (\text{Eq. A.2.1})$$

For the process costs, we can use the linearly approximated experience curve from Equation (6). Of course, the process costs depend only on the cumulated demand $D_{t,v,cum}^{std}$ covered by that process variant under consideration and not on the complete cumulated demand $D_{t,cum}^{std}$.

$$M_{v,t} = P_v - C_{v,0} + C_{v,0}\tilde{a}D_{t,v,cum}^{std} \quad (\text{Eq. A.2.2})$$

We now apply the assumption (A.2) of the constant demand weights and replace the cumulated demand $D_{t,v,\text{cum}}^{\text{std}}$ that was covered by process variant v starting from the decision point by the complete cumulated demand adjusted by the respective demand weight w_v^{std} .

$$M_{v,t} = P_v - C_{v,0} + C_{v,0} \tilde{\alpha} w_v^{\text{std}} D_{t,\text{cum}}^{\text{std}} \quad (\text{Eq. A.2.3})$$

The demand-weighted periodic profit margin M_t equals the demand-weighted variant-specific profit margins $M_{v,t}$ in period t , as shown in Equation (A.2.4).

$$\begin{aligned} M_t &= \sum_{v=0}^n w_v^{\text{std}} M_{v,t} = \sum_{v=0}^n w_v^{\text{std}} (P_v - C_{v,0} + C_{v,0} \tilde{\alpha} w_v^{\text{std}} D_{t,\text{cum}}^{\text{std}}) \\ &= \sum_{v=0}^n \left[w_v^{\text{std}} (P_v - C_{v,0}) + C_{v,0} \tilde{\alpha} D_{t,\text{cum}}^{\text{std}} (w_v^{\text{std}})^2 \right] \\ &= \sum_{v=0}^n w_v^{\text{std}} (P_v - C_{v,0}) + \tilde{\alpha} D_{t,\text{cum}}^{\text{std}} \sum_{v=0}^n (w_v^{\text{std}})^2 C_{v,0} = M_0 \\ &\quad + \tilde{\alpha} D_{t,\text{cum}}^{\text{std}} G_{\text{cost}} \end{aligned} \quad (\text{Eq. A.2.4})$$

$$\text{for } M_0 := \sum_{v=0}^n w_v^{\text{std}} (P_v - C_{v,0}) \text{ and } G_{\text{cost}} := \sum_{v=0}^n (w_v^{\text{std}})^2 C_{v,0}$$

B. Application of Anderson's Model (1994)

B.2 Linear Extrapolation for Process Quality (as an example)

As the two reference points $(x_1; y_1)$ and $(x_2; y_2)$ required to set up a linear extrapolation, we use the status quo and the case of complete standardization.

Reference point 1: $y_1 = Q$, $x_1 = G$

Reference point 2: $y_2 = (1 + s_Q) \cdot Q$, $x_2 = 1$

Based on these reference points, we can set up the linear extrapolation as shown in Equation (B.1.1).

$$y(x) = \frac{y_2 - y_1}{x_2 - x_1} (x - x_1) + y_1 \quad (\text{Eq. B.1.1})$$

The relationship between the Gini coefficient of a distinct process variant profile after BPS $G^{\text{std}} (= x)$ and the associated process quality $Q(G^{\text{std}}) (= y(x))$ can be determined by inserting the reference points into Equation (B.1.1) as shown in Equation (B.1.2):

$$Q(G^{\text{std}}) = \frac{Q \cdot (1 + s_Q) - Q}{1 - G} (G^{\text{std}} - G) + Q = \frac{Q \cdot s_Q}{1 - G} \Delta G + Q, \quad (\text{Eq. B.1.2})$$

for $\Delta G := (G^{\text{std}} - G)$

The change in process quality for a given Gini coefficient G^{std} after BPS equals:

$$Q(G^{\text{std}}) - Q = \frac{Q \cdot s_Q}{1 - G} \Delta G + Q - Q = \frac{Q \cdot s_Q}{1 - G} \Delta G \quad (\text{Eq. B.1.3})$$

The resulting relative change of process quality for a given Gini coefficient G^{std} after BPS compared to the status quo prior to BPS is shown in Equation (B.1.4).

$$\Delta Q(G) = \frac{Q(G^{\text{std}}) - Q}{Q} = \frac{\frac{Q \cdot s_Q}{1 - G} \Delta G}{Q} = \frac{s_Q}{1 - G} \Delta G \quad (\text{Eq. B.1.4})$$

B.2 Changes in Customer Satisfaction for a Given Gini Coefficient

According to Anderson's model of customer satisfaction and retention, the customer satisfaction SAT prior to BPS and after BPS can be expressed as shown in Equations (B.2.1) and (B.2.2).

$$SAT = \alpha_{SAT} + \beta_Q Q + \beta_{EXP} EXP + \beta_{NCD} NCD + \beta_{PCD} PCD + \varepsilon \quad (\text{Eq. B.2.1})$$

$$SAT(G^{\text{std}}) = \alpha_{SAT} + \beta_Q Q(G^{\text{std}}) + \beta_{EXP} EXP + \beta_{NCD} NCD(G^{\text{std}}) + \beta_{PCD} PCD(G^{\text{std}}) + \varepsilon \quad (\text{Eq. B.2.2})$$

We can now insert the derived functions for the model parameters given the Gini coefficient G^{std} as shown in Equation (B.2.3).

$$\begin{aligned} SAT(G^{\text{std}}) &= \alpha_{SAT} + \beta_Q Q \left(\frac{s_Q}{1 - G} \Delta G + 1 \right) + \beta_{EXP} EXP + \beta_{NCD} NCD \left(-\frac{s_Q + s_T}{1 - G} \Delta G + 1 \right) \\ &\quad + \beta_{PCD} PCD \left(\frac{s_Q + s_T}{1 - G} \Delta G + 1 \right) + \varepsilon \end{aligned} \quad (\text{Eq. B.2.3})$$

Based on these intermediate results, we can calculate the changes in customer satisfaction $\Delta SAT(G^{\text{std}})$ for a given Gini coefficient G^{std} after BPS as shown in Equation (B.2.4). The result can be found in Equation (13) in the manuscript.

$$\begin{aligned} \Delta SAT(G^{\text{std}}) &= SAT(G^{\text{std}}) - SAT \\ &= \alpha_{SAT} - \alpha_{SAT} + \beta_Q Q \left(\frac{s_Q}{1 - G} \Delta G + 1 \right) - \beta_Q Q + \beta_{EXP} EXP - \beta_{EXP} EXP \\ &\quad + \beta_{NCD} NCD \left(-\frac{s_T + s_Q}{1 - G} \Delta G + 1 \right) - \beta_{NCD} NCD \\ &\quad + \beta_{PCD} PCD \left(\frac{s_T + s_Q}{1 - G} \Delta G + 1 \right) - \beta_{PCD} PCD + \varepsilon - \varepsilon \\ &= \beta_Q \left(Q \frac{s_Q}{1 - G} \Delta G \right) + \beta_{NCD} \left(-NCD \frac{s_T + s_Q}{1 - G} \Delta G \right) \\ &\quad + \beta_{PCD} \left(PCD \frac{s_T + s_Q}{1 - G} \Delta G \right) \end{aligned} \quad (\text{Eq. B.2.4})$$

B.3. Changes in the Retention Rate for a Given Gini Coefficient

According to Anderson's model, the retention rate r prior to BPS and after BPS can be expressed as shown in Equations (B.3.1) and (B.3.2).

$$r = \alpha_r + \beta_{SAT}(SAT) + \varepsilon \quad (\text{Eq. B.3.1})$$

$$r(G^{\text{std}}) = \alpha_r + \beta_{SAT}SAT(G^{\text{std}}) + \varepsilon \quad (\text{Eq. B.3.2})$$

Based on this intermediate result, we can calculate the changes in retention rate $\Delta r(G^{\text{std}})$ for a given Gini coefficient G^{std} after BPS as shown in Equation (B.3.3).

$$\begin{aligned} \Delta r(G^{\text{std}}) &= r(G^{\text{std}}) - r = \alpha_r - \alpha_r + \beta_{SAT}(SAT(G^{\text{std}}) - SAT) + \varepsilon - \varepsilon \\ &= \beta_{SAT}\Delta SAT(G^{\text{std}}) \\ &= \beta_{SAT} \left(\beta_Q \left(Q \frac{S_Q}{1-G} \Delta G \right) + \beta_{NCD} \left(-NCD \frac{S_T + S_Q}{1-G} \Delta G \right) \right. \\ &\quad \left. + \beta_{PCD} \left(PCD \frac{S_T + S_Q}{1-G} \Delta G \right) \right) \\ &= \beta_{SAT}\beta_Q \left(Q \frac{S_Q}{1-G} \Delta G \right) + \beta_{SAT}\beta_{NCD} \left(-NCD \frac{S_T + S_Q}{1-G} \Delta G \right) \\ &\quad + \beta_{SAT}\beta_{PCD} \left(PCD \frac{S_T + S_Q}{1-G} \Delta G \right) \end{aligned} \quad (\text{Eq. B.3.3})$$

C. Objective Function

C.1 Simplification of the Cumulated Process Demand

The cumulated process demand $D_{t,\text{cum}}^{\text{std}}$ after BPS in period t can be defined as the sum of the periodic process demands D_t^{std} up to period t as shown in Equation (C.1.1).

$$D_{t,\text{cum}}^{\text{std}} = \sum_{j=0}^t D_j^{\text{std}} \quad (\text{Eq. C.1.1})$$

With $D_j = D_0(1 + \mu_D^{\text{std}})^j + \sigma Z_j$ for $Z_j \sim N(0,1)$ and $D_j^{\text{std}} = \delta D_j$ based on Equations (1) and (3) from the manuscript, we can insert the general demand model for the periodic process demands:

$$D_{t,\text{cum}}^{\text{std}} = \sum_{j=0}^t D_j^{\text{std}} = \sum_{j=0}^t \left[\delta D_0(1 + \mu_D^{\text{std}})^j + \delta \sigma Z_j \right]. \quad (\text{Eq. C.1.2})$$

In a next step, we divide Equation (C.1.2) into its deterministic part, i.e., $\sum_{j=0}^t \delta D_0(1 + \mu_D^{\text{std}})^j$, and its stochastic part, i.e., $\sum_{j=0}^t \delta \sigma Z_j = \delta \sigma \sum_{j=0}^t Z_j$. This leads to Equation (C.1.3).

$$\sum_{j=0}^t \left[\delta D_0 (1 + \mu_D^{\text{std}})^j + \delta \sigma Z_j \right] = \sum_{j=0}^t \delta D_0 (1 + \mu_D^{\text{std}})^j + \delta \sigma \sum_{j=0}^t Z_j \quad (\text{Eq. C.1.3})$$

Now we can analyze both parts in detail. The deterministic part is a geometric sequence. Therefore, we can apply the law of the partial sum of a geometric sequence to simplify the expression. The law for the partial sum of geometric sequence is defined as shown in Equation (C.1.4).

$$\sum_{j=0}^t a q^j = a \frac{1 - q^{t+1}}{1 - q} \quad (\text{Eq. C.1.4})$$

If we set the BPS-adjusted process demand $\delta D_0 =: a$ and the demand drift $1 + \mu_D^{\text{std}} =: q$, we can simplify the deterministic part of Equation (C.1.3) as shown in Equation (C.1.5).

$$\sum_{j=0}^t \delta D_0 (1 + \mu_D^{\text{std}})^j = \delta D_0 \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{1 - (1 + \mu_D^{\text{std}})} = \delta D_0 \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} \quad (\text{Eq. C.1.5})$$

According to assumption (A1), the stochastic part of Equation (C.1.3) equals the sum of t independent and identically normally distributed random variables with a mean of zero and a standard deviation of 1. Because of the reproduction property of the normal distribution, we know that the sum of normal distributions is again normally distributed. Therefore, Z_t^{sum} follows the distribution shown in Equation (C.1.6).

$$\delta \sigma \sum_{j=0}^t Z_j = \delta \sigma Z_t^{\text{sum}} \sim N \left(\delta \sigma \sum_{j=0}^t \mu(Z_j); \delta^2 \sigma^2 \sum_{j=0}^t \sum_{i=0}^t \sigma(Z_j) \sigma(Z_i) \rho_{i,j} \right); \quad (\text{Eq. C.1.6})$$

for $\rho_{i,j}$ be defined as the correlation coefficient

As the periodic process demand prior to BPS is observable, the deviation Z_0 at the decision point equals zero. Therefore, we can start with $j = 1$ as shown in Equation (C.1.7).

$$\delta \sigma \sum_{j=0}^t Z_j = \delta \sigma \sum_{j=1}^t Z_j = \delta \sigma Z_t^{\text{sum}} \quad (\text{Eq. C.1.7})$$

Additionally, it is known that the expected values for all periodic demand deviations equal zero, meaning that the expected value of the sum of all periodic deviations up to period t equals zero, too.

$$\mu(\delta \sigma Z_t^{\text{sum}}) = \delta \sigma \sum_{j=1}^t \mu(Z_j) = \delta \sigma \sum_{j=1}^t 0 = 0 \quad (\text{Eq. C.1.8})$$

Furthermore, we can use the independence between the periodic demand deviations from assumption (A1) and set their correlation coefficients equal to zero ($\rho_{i,j} = 0 \forall i, j \wedge i \neq j$). Thus, the variance of the sum of the periodic demand deviations $\sigma^2(Z_t^{\text{sum}})$ equals the sum of their variances as shown in Equation (C.1.9).

$$\begin{aligned} \sigma^2(\delta\sigma Z_t^{\text{sum}}) &= \delta^2\sigma^2 \sum_{j=1}^t \sum_{i=1}^t \sigma(Z_j)\sigma(Z_i)\rho_{i,j} = \delta^2\sigma^2 \sum_{j=1}^t \sigma^2(Z_j) = \delta^2\sigma^2 \sum_{j=1}^t 1 \\ &= \delta^2\sigma^2 t \end{aligned} \quad (\text{Eq. C.1.9})$$

Consequently, we can represent the stochastic part of Equation (C.1.3), i.e., $\delta\sigma Z_t^{\text{sum}}$, by a normally distributed random variable with a mean of zero and a variance of $\delta^2\sigma^2 t$. Recombining the stochastic and the deterministic part of Equation (C.1.3), we finally get Equation (C.1.10).

$$D_{t,\text{cum}}^{\text{std}} = \sum_{j=0}^t \left[\delta D_0 (1 + \mu_D^{\text{std}})^j + \delta\sigma Z_j \right] = \delta D_0 \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D} + \delta\sigma Z_t^{\text{sum}} \quad (\text{Eq. C.1.10})$$

C.2 Expected Value of the Periodic Cash Flows

As the periodic cash flows have stochastic and deterministic parts, we first expand the Equation (17) from the manuscript to facilitate the calculation of its expected value.

$$\begin{aligned} CF_t^{\text{std}} &= \left(\delta D_0 (1 + \mu_D^{\text{std}})^t + \delta\sigma Z_t \right) \left(M_0 + \tilde{a}G_{\text{cost}} \left(\delta\sigma Z_t^{\text{sum}} + \delta D_0 \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} \right) \right) \\ &= \delta D_0 (1 + \mu_D^{\text{std}})^t M_0 + \delta^2 D_0 (1 + \mu_D^{\text{std}})^t \tilde{a}G_{\text{cost}} \sigma Z_t^{\text{sum}} \\ &\quad + \delta^2 D_0^2 (1 + \mu_D^{\text{std}})^t \tilde{a}G_{\text{cost}} \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} + \delta\sigma Z_t M_0 \\ &\quad + \delta^2 \sigma^2 Z_t \tilde{a}G_{\text{cost}} Z_t^{\text{sum}} + \delta^2 \sigma Z_t D_0 \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} \end{aligned} \quad (\text{Eq. C.2.1})$$

Now, we can determine the expected value of the periodic process cash flows $E(CF_t^{\text{std}})$ as shown in Equation (C.2.2).

$$\begin{aligned} E(CF_t^{\text{std}}) &= E\left(\delta D_0 (1 + \mu_D^{\text{std}})^t M_0\right) + E\left(\delta^2 D_0 (1 + \mu_D^{\text{std}})^t \tilde{a}G_{\text{cost}} \sigma Z_t^{\text{sum}}\right) \\ &\quad + E\left(\delta^2 D_0^2 (1 + \mu_D^{\text{std}})^t \tilde{a}G_{\text{cost}} \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}}\right) + E(\delta\sigma Z_t M_0) \\ &\quad + E(\delta^2 \sigma^2 Z_t \tilde{a}G_{\text{cost}} Z_t^{\text{sum}}) + E\left(\delta^2 \sigma Z_t D_0 \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}}\right) \end{aligned} \quad (\text{Eq. C.2.2})$$

In a next step, we eliminate all components whose expected value equals zero and replace the expected values of deterministic terms by their values. The result is shown in Equation (C.2.3)

$$E(CF_t^{\text{std}}) = \delta D_0 (1 + \mu_D^{\text{std}})^t M_0 + \delta^2 D_0^2 (1 + \mu_D^{\text{std}})^t \tilde{a} G_{\text{cost}} \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} + E(\delta^2 \sigma^2 Z_t \tilde{a} G_{\text{cost}} Z_t^{\text{sum}}) \quad (\text{Eq. C.2.3})$$

Now, we calculate the expected value $E(\delta^2 \sigma^2 Z_t \tilde{a} G_{\text{cost}} Z_t^{\text{sum}})$. First of all, the deterministic variables can be put outside of the expected value operator as shown in Equation (C.2.4).

$$E(\delta^2 \sigma^2 Z_t \tilde{a} G_{\text{cost}} Z_t^{\text{sum}}) = \delta^2 \sigma^2 \tilde{a} G_{\text{cost}} E(Z_t Z_t^{\text{sum}}) \quad (\text{Eq. C.2.4})$$

What remains is the expected value of a product of two random variables. Determining the expected value of a product of two random variables requires applying the covariance formula from Equation (C.2.5). The result is shown in Equation (C.2.6).

$$\text{COV}(X, Y) = E(XY) - E(X)E(Y) \Leftrightarrow E(XY) = \text{COV}(X, Y) + E(X)E(Y) \quad (\text{Eq. C.2.5})$$

$$E(Z_t Z_t^{\text{sum}}) = \text{COV}(Z_t, Z_t^{\text{sum}}) + E(Z_t)E(Z_t^{\text{sum}}) = \text{COV}(Z_t, Z_t^{\text{sum}}) \quad (\text{Eq. C.2.6})$$

Considering the definition of the term Z_t^{sum} as the sum of the independent random deviations from the demand trend, we can divide it up into the cumulated deviations up to the period $t - 1$, Z_{t-1}^{sum} , and the deviation in period t , which is Z_t .

$$\text{COV}(Z_t, Z_t^{\text{sum}}) = \text{COV}(Z_t, Z_{t-1}^{\text{sum}} + Z_t) \quad (\text{Eq. C.2.7})$$

On this foundation, we can use the linearity of the covariance to simplify Equation (C.2.6) as follows.

$$\text{COV}(Z_t, Z_{t-1}^{\text{sum}} + Z_t) = \text{COV}(Z_t, Z_{t-1}^{\text{sum}}) + \text{COV}(Z_t, Z_t) \quad (\text{Eq. C.2.8})$$

Considering that the covariance of a random variable with itself equals its variance and that the periodic deviation Z_t is independent from the cumulated deviations, i.e., $\text{COV}(Z(0,1); Z(0, t-1)) = 0$, we can simplify Equation (C.2.8) as shown in Equation (C.2.9).

$$\text{COV}(Z_t, Z_{t-1}^{\text{sum}}) + \text{COV}(Z_t, Z_t) = \sigma^2(Z_t) = 1 \quad (\text{Eq. C.2.9})$$

Now we can determine the expected periodic cash flows as shown in Equation (C.2.10).

$$E(CF_t^{\text{std}}) = \delta D_0 (1 + \mu_D^{\text{std}})^t M_0 + \delta^2 D_0^2 (1 + \mu_D^{\text{std}})^t \tilde{a} G_{\text{cost}} \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} + \delta^2 \sigma^2 \tilde{a} G_{\text{cost}} \quad (\text{Eq. C.2.10})$$

C.3 Present Value of the Expected Periodic Cash Flows

The present value of the expected periodic cash flows equals:

$$PV = \sum_{t=0}^{\tau} \frac{1}{(1+i)^t} \left[\delta D_0 (1 + \mu_D^{\text{std}})^t M_0 + \delta^2 D_0^2 (1 + \mu_D^{\text{std}})^t \tilde{a} G_{\text{cost}} \frac{1 - (1 + \mu_D^{\text{std}})^{t+1}}{-\mu_D^{\text{std}}} + \delta^2 \sigma^2 \tilde{a} G_{\text{cost}} \right] \quad (\text{Eq. C.3.1})$$

The first step to simplify Equation (C.3.1) is to separate the total sum into different summands as shown in Equation (C.3.2).

$$PV = \sum_{t=0}^{\tau} \delta D_0 M_0 \frac{(1 + \mu_D^{\text{std}})^t}{(1+i)^t} + \sum_{t=0}^{\tau} \frac{\delta^2 D_0^2 \tilde{a} G_{\text{cost}} (1 + \mu_D^{\text{std}})^t}{-\mu_D^{\text{std}} (1+i)^t} - \sum_{t=0}^{\tau} \frac{\delta^2 D_0^2 \tilde{a} G_{\text{cost}}}{-\mu_D^{\text{std}}} (1 + \mu_D^{\text{std}}) \left(\frac{1 + \mu_D^{\text{std}}}{(1+i)^t} \right)^{2t} + \sum_{t=0}^{\tau} \delta^2 \sigma^2 \tilde{a} G_{\text{cost}} \frac{1}{(1+i)^t} \quad (\text{Eq. C.3.2})$$

Each of the summands is a geometric sequence. Consequently, the law for the partial sum of the geometric sequence can be applied. The present value of each summand can be obtained by inserting the starting point of each geometric sequence and its growth factor as shown in Equation (C.3.3).

$$PV = \left(\delta D_0 M_0 + \frac{\delta^2 D_0^2 \tilde{a} G_{\text{cost}}}{-\mu_D^{\text{std}}} \right) \frac{1 - \frac{(1 + \mu_D^{\text{std}})^{\tau+1}}{(1+i)^{\tau+1}}}{1 - \frac{1 + \mu_D^{\text{std}}}{1+i}} - \frac{\delta^2 D_0^2 \tilde{a} G_{\text{cost}}}{-\mu_D^{\text{std}}} (1 + \mu_D^{\text{std}}) \frac{1 - \left[\frac{(1 + \mu_D^{\text{std}})^2}{(1+i)} \right]^{\tau+1}}{1 - \frac{(1 + \mu_D^{\text{std}})^2}{(1+i)}} + \delta^2 \sigma^2 \tilde{a} G_{\text{cost}} \frac{1 - \frac{1}{(1+i)^{\tau+1}}}{1 - \frac{1}{1+i}} \quad (\text{Eq. C.3.3})$$

C.4 Final Objective Function including the Investment Outflows

Taking all intermediate results and the investment outflows from Equation (20) in the manuscript together, leads to the following final definition of objective function:

MAX:

$$NPV = PV - I =$$

$$\left(\delta D_0 M_0 + \frac{\tilde{\alpha} G_{\text{cost}} \delta^2 D_0^2}{-\mu_D^{\text{std}}} \right) \frac{1 - \frac{(1 + \mu_D^{\text{std}})^{\tau+1}}{(1+i)^{\tau+1}}}{1 - \frac{1 + \mu_D^{\text{std}}}{1+i}} - \frac{\tilde{\alpha} G_{\text{cost}} \delta^2 D_0^2}{-\mu_D^s} (1 + \mu_D^{\text{std}}) \frac{1 - \left[\frac{(1 + \mu_D^{\text{std}})^2}{(1+i)} \right]^{\tau+1}}{1 - \frac{(1 + \mu_D^{\text{std}})^2}{(1+i)}} \\ + \tilde{\alpha} \delta^2 G_{\text{cost}} \sigma^2 \frac{1 - \frac{1}{(1+i)^{\tau+1}}}{1 - \frac{1}{1+i}} - I$$

where:

$$\delta = \sum_{c=1}^n w_c \left[(1 - f_c)^{(x_c - x_c^{\text{std}})} \right]$$

$$M_0 = \sum_{v=0}^n w_v^{\text{std}} (P_v - C_{v,0})$$

$$w_c^{\text{std}} = \frac{w_c \left[(1 - f_c)^{(x_c - x_c^{\text{std}})} \right]}{\delta}$$

$$G_{\text{cost}} = \sum_{v=0}^m (w_v^{\text{std}})^2 C_{v,0}$$

$$w_v^{\text{std}} = x_c \frac{w_c \left[(1 - f_c)^{(x_c - x_c^{\text{std}})} \right]}{\delta}$$

$$G = \sum_{v=0}^n (w_v^{\text{std}})^2$$

$$w_0^{\text{std}} = 1 - \sum_{v=1}^n w_v^{\text{std}}$$

$$I = \sum_{c=1}^n |x_c - x_c^{\text{std}}| I_c$$

$$\mu_D(G^{\text{std}}) = \mu_D + \Delta r(G^{\text{std}})$$

$$= \mu_D + \beta_{\text{SAT}} \left[\beta_Q \left(Q \frac{S_Q}{1-G} \right) \Delta G + \beta_{\text{NCD}} \left(-\text{NCD} \frac{S_T + S_Q}{1-G} \right) \Delta G + \beta_{\text{PCD}} \left(\text{PCD} \frac{S_T + S_Q}{1-G} \right) \Delta G \right]$$

subject to:

$$x_c^{\text{std}} \in \{0; 1\} \text{ and } R$$

D. Questionnaire and Responses for the Real-World Case

Demand of the coverage switching processes
How many process instances were executed in the last period?
9,875
How will the periodic demand relatively increase or decrease over the planning horizon?
+10% per year
What is the standard deviation of the periodic demand?
1,200 per year

Execution options of the coverage switching processes			
What is the average revenue of the integration of one contract?			
90.00 EUR			
Execution option	Fraction of the demand covered by this execution option	Costs per execution	What fraction of the currently connected brokers would leave if this execution option were eliminated?
Submission of end-customer information in electronic form	30%	20.00 EUR	5%
Submission of end-customer information in paper form	70%	25.00 EUR	5%
Broker updates information	70%	11.25 EUR	25%
Call center updates information	30%	37.50 EUR	0%
Broker changes contract	80%	3.75 EUR	25%
Call center changes contract	20%	12.50 EUR	0%

Experience curve effects
How high were the average costs per execution in the last period?
48.25 EUR

How did the average execution costs change in the last period?
- 2.50 EUR

Process quality and time from Anderson's model
How do you rate the current process quality on a 10 point scale? (1 = very low,..., 10 = very high)
8
By what percentage would the process quality improve due to BPS?
+12.50%
By what percentage would the process time improve due to BPS?
+63.33%

Company-specific adjustment factors from Anderson's model		
Adjustment factor	Derivation	Values
Concentration (CONC)	The inverse of the number of competitors comprising 70 percent of the sales in the industry	20
Ease of evaluating quality (QEVAl)	How difficult or easy is it to evaluate quality (1 = very difficult,..., 10 = very easy)?	8
Differentiation (DIFF)	How strongly do you differ from your competitors on a scale from 1 to 10 (1 = very weak,..., 10 = very strong)?	4
Involvement (INVOLV)	How would you rate the involvement of your customers on a scale from 1 to 10 (1 = very low,..., 10 = very high)?	3
Frequency of usage (USAGE)	How would you rate the frequency of your customers' usage of the integration process on a scale from 1 to 10 (1 = very low,..., 10 = very high)?	5
Switching costs (SC)	How would you rate your customers' switching costs on a scale from 1 to 10 (1 = very low,..., 10 = very high)?	3
Difficulty of standardization (DSTD)	How would you rate the standardization difficulty within your industry on a scale from 1 to 10 (1 = very low,..., 10 = very high)?	9

Further parameters
What is the planning horizon for investment decisions within your company?
7 years

What is the risk-adjusted discount rate for investment decisions within your company?

4% per year

Process quality and time from Anderson’s model (using process variant 3 as master process)

By what percentage would the process quality improve due to BPS?

-10.00%

By what percentage would the process time improve due to BPS?

-30.00%

Process quality and time from Anderson’s model (using process variant 4 as master process)

By what percentage would the process quality improve due to BPS?

+11.25%

By what percentage would the process time improve due to BPS?

+57.00%

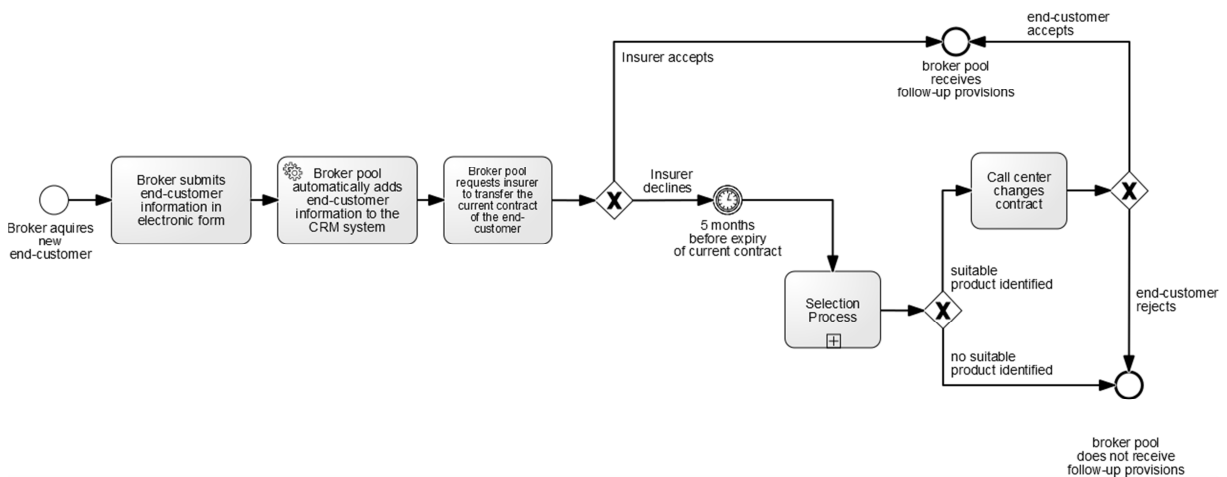


Figure 1: The master process (basic scenario)

E. Sensitivity Analysis (Basic Scenario)

E.1 Adjusted Values of the Objective Function

	Quality Effect	Time Effect	Demand Drift	Demand
-0.5	4,380,780	4,380,927	3,650,498	2,115,078
-0.4	4,380,912	4,381,029	3,784,457	2,556,206
-0.3	4,381,043	4,381,131	3,924,260	3,003,406
-0.2	4,381,175	4,381,233	4,070,170	3,456,678
-0.1	4,381,306	4,381,336	4,222,465	3,916,022
0.1	4,381,569	4,381,540	4,547,392	4,852,926
0.2	4,381,701	4,381,642	4,720,648	5,330,486
0.3	4,381,832	4,381,745	4,901,542	5,814,119
0.4	4,381,964	4,381,847	5,090,427	6,303,823
0.5	4,382,096	4,381,949	5,287,671	6,799,599
Opt. Profile	no changes	no changes	no changes	no changes

	Demand Variance	Learning Curve	Planning Horizon	Quality
-0.5	4,381,179	4,229,378	2,146,961	4,380,881
-0.4	4,381,231	4,259,790	2,547,911	4,380,993
-0.3	4,381,282	4,290,202	2,970,308	4,381,104
-0.2	4,381,334	4,320,614	3,415,614	4,381,215
-0.1	4,381,386	4,351,026	3,885,416	4,381,327
0.1	4,381,490	4,411,850	4,905,559	4,381,549
0.2	4,381,542	4,442,262	5,459,823	4,381,661
0.3	4,381,593	4,472,674	6,046,462	-
0.4	4,381,645	4,503,086	6,667,909	-
0.5	4,381,697	4,533,498	7,326,822	-
Opt. Profile	no changes	no changes	no changes	no changes

E.2 Delta compared to the Status Quo

	Quality Effect	Time Effect	Demand Drift	Demand
-0.5	20,361	20,507	17,296	9,835
-0.4	20,492	20,609	17,974	11,963
-0.3	20,624	20,711	18,683	14,146
-0.2	20,755	20,813	19,426	16,382
-0.1	20,886	20,916	20,203	18,673
+0.1	21,150	21,120	21,872	23,417
+0.2	21,281	21,223	22,766	25,870
+0.3	21,413	21,325	23,703	28,378
+0.4	21,544	21,427	24,686	30,939
+0.5	21,676	21,529	25,716	33,554
Opt. Profile	no changes	no changes	no changes	no changes

	Demand Variance	Learning Curve	Planning Horizon	Quality
-0.5	21,016	19,663	9,426	20,461
-0.4	21,016	19,934	11,381	20,573
-0.3	21,017	20,205	13,501	20,684
-0.2	21,017	20,476	15,803	20,795
-0.1	21,018	20,747	18,302	20,907
+0.1	21,018	21,289	23,972	21,129
+0.2	21,019	21,560	27,185	21,241
+0.3	21,019	21,831	30,685	-
+0.4	21,020	22,102	34,499	-
+0.5	21,020	22,373	38,658	-
Opt. Profile	no changes	no changes	no changes	no changes

F. Glossary

BPS-specific variables

std Superscript indicating a variable's value after BPS

G_{cost} Cost-weighted Gini Coefficient

G Gini Coefficient

Process Variants and Contexts Variables

v A distinct process variant

c A distinct process context

w_c Demand weight of a process context

n Total number of process contexts

M_t Profit margin in period t

Demand Model

D_t Periodic process demand

μ_D Demand trend

Z_t Periodic demand deviation

σ Standard deviation of the periodic demand deviations

Demand Effects of BPS

f_c Fraction of demand for process context c that can only be tapped by the corresponding process variant v

δ Total relative change in the process demand due to BPS

w_v^{std} Demand weight covered by process variant v

w_0^{std} Demand weight covered by the master process

Learning Curve

D_{cum} Cumulated demand

a Elasticity of the process costs regarding the cumulated demand

K	Process costs of for the first output
C	Process costs
$D_{0,cum}$	Cumulated process demand up to the decision point
$\tilde{\alpha}$	Adjusted elasticity of the process costs regarding the cumulated demand
$D_{t,cum}^{std}$	Cumulated process demand that has been reached starting from the decision point up to period t
Quality and Time Effects	
Q	Process quality
T	Process time
s_Q	Relative increase in process quality in case of complete standardization compared to the status prior to BPS
s_T	Relative increase in process time in case of complete standardization compared to the status prior to BPS
SAT	Customer satisfaction
EXP	Customer expectation
NCD	Negative Confirmation/Disconfirmation
PCD	Positive Confirmation/Disconfirmation
β_Q	Sensitivity of customer satisfaction w.r.t. process quality
β_{NCD}	Sensitivity of customer satisfaction w.r.t. negative confirmation/-disconfirmation
β_{PCD}	Sensitivity of customer satisfaction w.r.t. positive confirmation/disconfirmation
r	Retention rate
β_{SAT}	Sensitivity of retention rate w.r.t. customer satisfaction
Objective Function	
x_c	Decision variable indicating that process context c is covered by the respective process variant ($x_c = 1$) or the master process ($x_c = 0$) prior to BPS
x_c^{std}	Decision variable indicating that process context c is covered by the respective process variant ($x_c = 1$) or the master process ($x_c = 0$) after to BPS
CF_t	Periodic process cash flows in period t
t	A distinct period within the planning horizon
τ	Total planning horizon
i	Risk-adjusted interest rate
I	Overall investment outflows
I_c	Investment outflows for process context c
PV	Risk-adjusted expected present value
NPV	Risk-adjusted expected net present value
R	Set of constraints regarding admissible values of x_c^{std}

V.2 The Business Value of Process Flexibility - An Optimization Model and its Application in the Service Sector.

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Abstract

Promising to cope with increasing demand variety and uncertainty, flexibility in general and process flexibility in particular are becoming ever more desired corporate capabilities. During the last years, the business process management and the production/operations management communities have proposed numerous approaches that investigate how to value and determine an appropriate level of process flexibility. Most of these approaches are very restrictive regarding their application domain, neglect characteristics of the involved processes and outputs other than demand and capacity, and do not conduct a thorough economic analysis of process flexibility. Against this backdrop, the authors propose an optimization model that determines an appropriate level of process flexibility in line with the principles of value-based business process management. The model includes demand uncertainty, variability, criticality, and similarity as process characteristics. The paper also reports on the insights gained from applying the optimization model to the coverage switching processes of an insurance broker pool company.

V.2.1 Introduction

In a world where many companies face strong competition, flexibility is becoming an ever more desired corporate capability (van der Aalst 2013). In particular, flexible processes promise to cope with increasing demand variety and uncertainty (Goyal and Netessine 2011). More flexible processes, however, are not necessarily better (He et al. 2012). Rather, the appropriate level of process flexibility depends on the characteristics of the business environment and of the involved processes as well as on the economic effects that go along with investing in process flexibility (Neuhuber et al. 2013; van Biesebroeck 2007).

Due to the importance of process flexibility, many researchers have already investigated how to value and determine an appropriate level of process flexibility. The related work consists of two streams. In the first stream, processes are interpreted as business processes, i.e., coordinated sets of tasks for achieving a particular result, as it is typical for the business process management (BPM) community (Dumas et al. 2013). In the second stream, processes are restricted to the manufacturing domain. With most approaches originating from the capacity-flexibility and the production/operations management literature, determining the optimal level of process flexibility is treated as a product-plant allocation problem.

As for the first stream, Braunwarth et al. (2010) help insurance companies determine at runtime whether claims should be handled automated or manually and flexibly. Their optimization model relies on the expected present value of the short-time cash effects and the hard-to-measure long-term effects on customer satisfaction. Due to its focus on runtime decision support, the model neglects the investments required to establish process flexibility. Braunwarth and Ullrich (2010) propose a model that supports service providers in deciding whether cases should be executed in-house or routed to an external service provider depending on the workload. Neuhuber et al. (2013) determine the optimal level of volume and functional flexibility of a service process to prepare the selection of flexibility projects. Despite its focus on the positive economic effects of process flexibility, the model only accounts for a single period and deterministic cash flows. As for the second stream, Jordan and Graves (1995) investigate the benefits of process flexibility. They found that limited process flexibility leads to almost the same benefits as total flexibility in terms of capacity utilization and increased expected sales. Despite seminal results, their analysis is restricted to demand and capacity information, neglects negative effects of process flexibility, and abstracts from an economic evaluation. He et al. (2012) treat process flexibility as the ability

to reallocate capacity between process outputs. Extending Jordan and Graves (1995), their model includes the demand correlations between different outputs when identifying the need for process flexibility. However, they also neglect that flexibility requires investments, that the ability to reallocate capacity depends on the involved processes and outputs, and that reallocating capacity also has economic effects. Further, they treat process flexibility as a binary concept, i.e., a process is either flexible or not. Tanrisever et al. (2012) incorporate on-going costs and a multi-period planning horizon. Nevertheless, they still disregard relevant process characteristics and investments.

The preceding review makes the following research gap apparent: First, current optimization models that deal with process flexibility are either restricted to the manufacturing area or focus on processes from specific application domains. Characteristics of the involved processes and outputs other than capacity and demand that influence the appropriate level of process flexibility are barely considered. What is missing is a more general guidance that abstracts from the peculiarities of distinct application domains and extends beyond demand and capacity information. Second, most existing optimization models either neglect the economic effects of process flexibility or only consider how process flexibility reduces costs. Most approaches considering the positive economic effects of process flexibility do this in a coarse-grained and hard-to-measure way or neglect the stochastic and long-term nature of these effects. Therefore, a thorough economic analysis of process flexibility decisions is missing.

In this paper, we propose an optimization model that addresses both issues of the research gap. The model considers two processes, one with an inferior and the other with a superior output in terms of profit margin. In line with the existing literature (e.g., He et al. 2012), process flexibility refers to the fraction of capacity that may be reallocated from one process to another. To determine how flexible both processes should be, the model analyzes which fractions of flexible capacity maximize the risk-adjusted expected net present value (NPV), a quantity compliant with the principles of value-based BPM. Thus, the model accounts for positive and negative economic effects of process flexibility such as investment outflows, increased cash inflows from selling more superior outputs, and opportunity costs caused by reallocating capacity. Furthermore, the model is broadly applicable as it incorporates parameters whose values can be easily assessed. These parameters include a uniformly distributed demand for the process outputs and process characteristics like similarity, criticality, and variability. The focus on two processes and a uniformly distributed demand allows for systematically structuring the optimization problem from an economic

perspective, for incorporating the cash effects of relevant parameters, and for analytically deriving an optimal level of process flexibility. With this paper, we also contribute to the process improvement area where novel approaches – particularly those that take on an economic perspective and extend current decision-making capabilities – are in high demand (van der Aalst 2013; vom Brocke et al. 2011) We also extend our prior work by relaxing some assumptions, by considering both processes as flexible, and by providing a real-world example from the services sector (Afflerbach et al. 2013).

We proceed as follows: In section 2, we outline the theoretical background of process flexibility and value-based BPM. In sections 3 and 4, we present the optimization model and report on insights gained from applying the model to the coverage switching processes of an insurance broker pool company. In section 5, we discuss limitations and point to topics for future research.

V.2.2 Theoretical background

V.2.2.1 Foundations of process flexibility

Flexibility is an immature concept whose vagueness resulted in an abundance of definitions (de Toni and Tochia 1998; Saleh et al. 2009; Sethi and Sethi 1990). There are both very generic definitions that do not allow for concrete measurement and highly specific definitions that focus on single facets of flexibility (Johnston and Clark 2005; Zelenovic 1982). In general, flexibility can be treated as the ability of a “system to react to or to anticipate system or environmental changes by adapting its structure and/or its behavior considering given objectives” (Wagner et al. 2011a, p. 811).

We define process flexibility by using an adapted version of Goyal and Netessine’s (2011) definition of product flexibility, an analogy that is reasonable as processes also create value-added output (Dumas et al. 2013). Accordingly, process flexibility refers to the *ability to create multiple outputs on the same capacity and to reallocate capacity between processes in response to realized demand*. As defined here, process flexibility leads to volume flexibility that is achieved by making the involved processes functionally flexible using a flexibility-by-design strategy. Volume flexibility enables increasing and decreasing production above and below the installed capacity (Goyal and Netessine 2011). Functional flexibility makes it possible to deliver the desired output variety (Anupindi et al. 2012). Flexibility-by-design, as a particular strategy to implement functional flexibility, requires incorporating alternative execution paths in a process model at design time and selecting the

most appropriate path at runtime (Schonenberg et al. 2008). Our definition of process flexibility fits the general definition from Wagner et al. (2011a) as it requires adapting the structure and behavior of the involved processes to enable reallocating capacity and coping with anticipated environmental uncertainty in terms of risky demand. The advantage of our definition is that the level of process flexibility can be easily measured. It also abstracts from concrete flexibility projects and applies to many processes as it only requires a high-level knowledge about the involved processes. Finally, our definition complies with other definitions of process flexibility such as those proposed by He et al. (2012), Iravani et al. (2005), or Jordan and Graves (1995).

When implementing process flexibility as defined here, it is worthwhile to look at how functional flexibility, particularly flexibility-by-design, is implemented. Functional flexibility has a rich tradition in BPM and workflow management as well as in capacity and workforce management (Kumar and Narasipuram 2006; Reichert and Weber 2012). From a process design perspective, flexibility-by-design can be implemented via configurable process models (Gottschalk et al. 2007). From a resource perspective, flexibility-by-design can be achieved via cross-training, multi-skilling, multi-purpose machines, IT-based assistance systems, and process-aware information systems (Iravani et al. 2005; Reichert and Weber 2012).

There are several characteristics that drive the need for process flexibility. Gebauer and Schober (2006) characterize a process by means of time-criticality, variability, and uncertainty. Time-criticality equals the fraction of time-critical tasks. Variability measures how frequently different process variants are performed. Uncertainty splits into environmental uncertainty (e.g., risky demand) and structural uncertainty (e.g., risks from within the process). He et al. (2012) also rely on uncertainty as a driver of process flexibility. Pujawan (2004) determines internal and external drivers of process flexibility, e.g., product variety and process similarity. Reichert and Weber (2012) present characteristics that determine the need for flexible processes supported by a process-aware information system, e.g., variability and looseness in the sense of uncertainty. Finally, Wagner et al. (2011b) present eight characteristics that drive the need for process flexibility, e.g., the cycle time of a process and the time between planning and execution. We incorporate uncertainty, variability, similarity, and criticality as the most popular drivers of process flexibility.

Another often-discussed issue is the relationship between process flexibility and standardization. Depending on the context, this relationship can be interpreted as conflicting or complementary. On the one hand, process flexibility and standardization can be treated as conflicting as standardization may reduce the number of process variants and prohibit deviating from these variants, whereas more process variants and degrees of freedom during execution help cope with a higher desired output variety (Pentland 2003). On the other hand, process flexibility and standardization can be seen as complementary, for instance if processes are defined in a way that enables assembling suitable processes at runtime and changing processes more easily (Muenstermann et al. 2010; Schonenberg et al. 2008). In our multi-process context at hand, we treat process flexibility and standardization as complementary for two reasons. First, in line with the flexibility-by-design strategy, we require the variants, i.e. standardized execution paths, of each involved process to be known on a high level at design time. This can be reasonably assumed for standard and routine processes (Lillrank 2003). Second, we define a process as flexible if its capacity can be reallocated to create the output of other processes. Obviously, capacity can be reallocated more easily if other processes are more standardized, i.e., less variants have to be supported.

V.2.2.2 Value-based business process management

Value-based BPM is a paradigm where all process-related activities and decisions are valued according to their contribution to the company value (Buhl et al. 2011). Thereby, value-based BPM applies the principles from value-based management (VBM) to process decision-making. Building on the work of Rappaport (1986), Copeland et al. (1990) as well as Stewart and Stern (1991), for VBM the primary objective for all business activities is to maximize the long term company value. The company value is based on future cash flows (Rappaport 1986). In order to claim VBM to be implemented, companies must be able to quantify their value on the aggregate level as well as the value contribution of single activities and decisions. To comply with VBM, decisions must be based on cash flows, consider risks, and incorporate the time value of money (Buhl et al. 2011). There is a set of objective functions that can be used for value-based decision-making (Berger 2010). In case of certainty, decisions can be based on the NPV of the future cash flows. In case of risk with risk-neutral decision-makers, decisions can be made based on the expected NPV. If decision-makers are risk-averse, decision alternatives can be valued using the certainty equivalent method or a risk-adjusted interest rate. As we intend to capture the effects of uncertainty, we use an expected NPV with a risk-adjusted interest rate.

V.2.3 Optimization model

V.2.3.1 General setting

We consider two processes operated by the same company. One process creates an inferior output, the other process a superior output. We refer to the process with the inferior output as inferior process, to the process with the superior output as superior process. Each process has a fixed capacity $C_{\text{sup/inf}} \in \mathbb{R}^+$. The demands $X_{\text{sup/inf}}$ for both outputs are assumed to be uniformly distributed in $[C_{\text{sup/inf}} - D_{\text{sup/inf}}^-, C_{\text{sup/inf}} + D_{\text{sup/inf}}^+]$, where $D_{\text{sup/inf}}^- \in \mathbb{R}^+$ and $D_{\text{sup/inf}}^+ \in \mathbb{R}^+$ denote the highest possible shortfall and excess demands relative to the capacities. The demand for both outputs is also assumed to be independent from each other. Finally, the periodic demands for each output are assumed to be independent and identically distributed.

Assumption 1: The demand for the inferior and the superior process output is uniformly distributed.

Although the normal distribution is a more standard way to model risky demand and has already been applied to process flexibility (He et al. 2012), we chose the uniform distribution. In fact, our model could not be solved analytically if a normally distributed demand were assumed because the required distribution function can only be approximated for a normally distributed demand. However, the uniform distribution can be fitted to the normal distribution in terms of expected value, standard deviation, and skewness. The normal distribution, however, has a larger kurtosis, i.e., demand realizations close to the expected value are more probable for a uniformly distributed demand. Thus, the model tends to underestimate the effect of process flexibility.

Assumption 2: The demand for the inferior output is independent from that for the superior output. The periodic demands for both process outputs are independent and identically distributed.

We assumed the demand to be independent across process outputs and time to reduce the complexity of our model and to be able to determine the optimal level of process flexibility for each process separately (Jordan and Graves 1995). If the demand for the process outputs depended positively (negatively), we would overestimate (underestimate) the effect of process flexibility. As companies are able to capture systematic dependencies in their capacity strategy (Zhang et al. 2003), the periodic noise can be reasonably treated as independent.

Enabling the reallocation of capacity, process flexibility is measured as the fraction of the capacity that can be used to produce the output of the other process. In this context, two decisions have to be made: an investment decision on the flexibility potential $F_{\text{sup/inf}} \in [0; 1]$ that is established for each process at the beginning of the planning horizon and an execution decision on the level of flexibility realized in each period $f_{\text{sup/inf}} \in [0; F_{\text{sup/inf}}]$. We use flexibility potential and flexibility as synonyms. This definition of process flexibility enables modeling the additional capacity of one process based on the flexibility and the capacity of the other process. To transform the provided capacity into additional capacity units, we use an exchange rate $T \in \mathbb{R}^+$. The exchange rate indicates how many units of the superior output can be produced by reallocating one capacity unit of the inferior process.

Process flexibility impacts cash inflows and outflows. As for the cash inflows, we need the profit margins of both process outputs $M_{\text{sup/inf}} \in \mathbb{R}^+$. Thereby, the profit margin of the superior output is higher than that of the inferior output ($M_{\text{sup}} > M_{\text{inf}}$). We assume the profit margins to be constant over time and the amount of outputs sold. This complies with cost-plus-pricing, an approach where companies add a fixed margin to the production costs to obtain the sales price (Arrow 1962; Guilding et al. 2005). As a result, additional sales volume directly translates into additional cash inflows. Likewise, capacity shortages translate into reduced cash inflows. Cash outflows, in contrast, result from implementing flexibility projects such as those sketched in the theoretical background.

Assumption 3: The profit margins are constant over time and over the sold amount of outputs.

In line with value-based BPM, we aim at maximizing the risk-adjusted expected NPV that goes along with investing in process flexibility. Our objective function equals the risk-adjusted expected NPV of the cash inflows $I \in \mathbb{R}_0^+$ and the cash outflows $C \in \mathbb{R}_0^+$.

$$\text{MAX: } I_{\text{sup}}(F_{\text{sup}}) + I_{\text{inf}}(F_{\text{inf}}) - C(F_{\text{sup}}) - C(F_{\text{inf}}) \quad (1)$$

Below, we substantiate the objective function by modeling its components in detail. We then solve the optimization model and present the optimal levels of process flexibility for both processes.

V.2.3.2 Cash inflow effects of process flexibility

The cash inflow effects of process flexibility result from different demand realizations. By determining whether and in which direction capacity should be reallocated, the cash inflow

effects for different demand realizations can be analyzed. As for the inferior process whose capacity supports the superior process, expected inflow increases from selling more superior outputs and decreases from selling less inferior outputs have to be considered. As for the superior process whose capacity supports the inferior process, only expected inflow increases from selling more inferior outputs have to be considered. Reduced inflows from selling less superior outputs are not reasonable as the profit margin of the superior output is higher than that of the inferior product. As a foundation for calculating the expected inflow effects, we investigate the stochastic implied by different demand realizations based on the decision tree shown in Fig. 1.

- **Case 1:** If the demand for the superior output exceeds the capacity of the superior process, the superior process requires capacity from the inferior process. Due to the higher profit margin of the superior output, capacity of the inferior process is always reallocated if needed. If the capacity requirements are such high that the inferior process cannot serve its own demand anymore, the resulting capacity shortage causes decreased inflows from selling less inferior outputs. Thus, another case distinction is necessary that accounts for the demand realizations for the inferior output. If the demand for the inferior output exceeds the capacity of the inferior process (case 1.1), there will definitely be a capacity shortage. If the demand for the inferior output realizes below the capacity of the inferior process (case 1.2), the inferior process has free capacity. That is, there is a chance that the free capacity is sufficient to meet the capacity requirements of the superior process without causing a capacity shortage at the inferior process.
- **Case 2:** If the demand for the superior output realizes below the capacity of the superior process, the superior process can serve its demand on its own. The flexibility of the inferior process is not used and does not cause additional inflows. Moreover, the superior process has free capacity that can be reallocated without negative effects. The inferior process only requires capacity from the superior process if the demand for the inferior output exceeds the capacity of the inferior process (case 2.1). In this case, the flexibility of the superior process causes additional inflows. If the demand for the inferior output realizes below the capacity of the inferior process (case 2.2), flexibility of the superior process has no inflow effects. Thus, this case is omitted from our analysis.

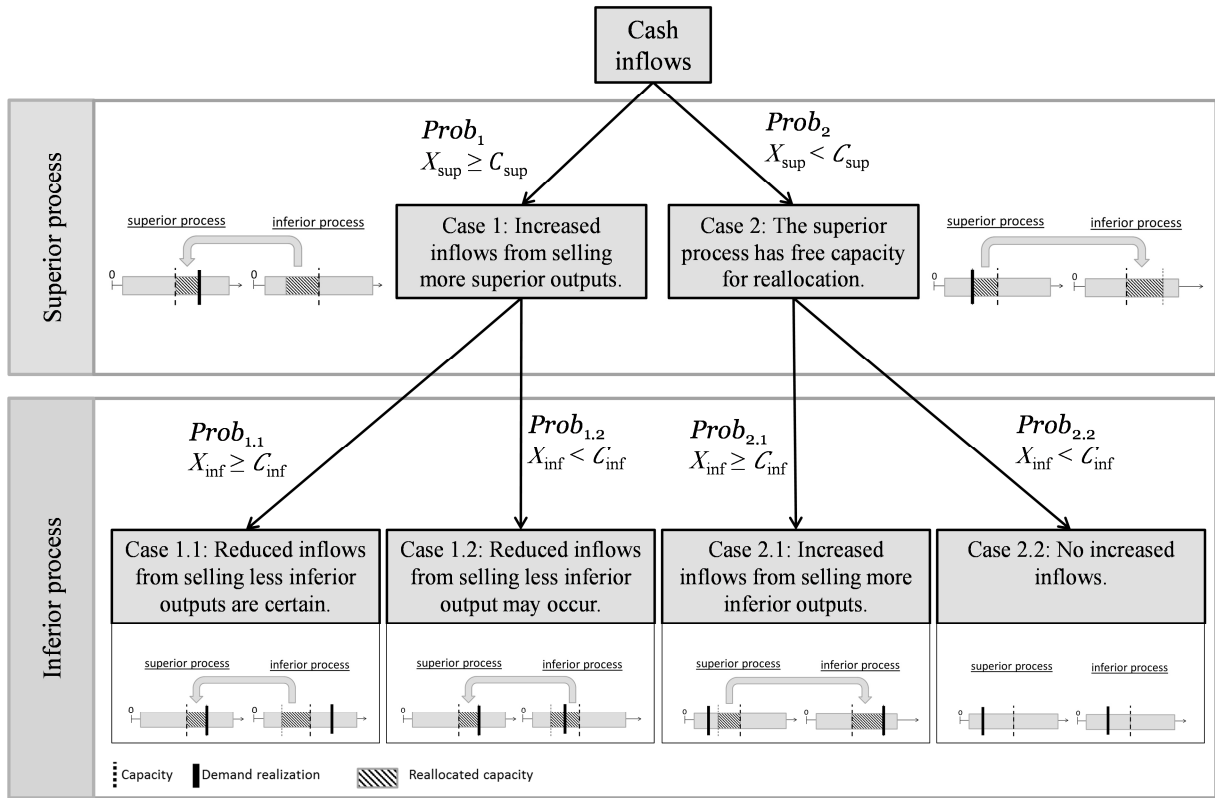


Fig. 1 Decision tree for determining the cash inflows effects

Each case occurs with a distinct probability that can be derived from the properties of the uniform distribution as well as the maximum excess and shortfall demands relative to the capacities:

$$Prob_1(X_{sup} \geq C_{sup}) = \frac{D_{sup}^+}{D_{sup}^- + D_{sup}^+} \tag{2}$$

$$Prob_{1.1}(X_{sup} \geq C_{sup}; X_{inf} \geq C_{inf}) = \frac{D_{sup}^+}{D_{sup}^- + D_{sup}^+} \frac{D_{inf}^+}{D_{inf}^- + D_{inf}^+} \tag{3}$$

$$Prob_{1.2}(X_{sup} \geq C_{sup}; X_{inf} < C_{inf}) = \frac{D_{sup}^+}{D_{sup}^- + D_{sup}^+} \frac{D_{inf}^-}{D_{inf}^- + D_{inf}^+} \tag{4}$$

$$Prob_{2.1}(X_{sup} < C_{sup}; X_{inf} \geq C_{inf}) = \frac{D_{sup}^-}{D_{sup}^- + D_{sup}^+} \frac{D_{inf}^+}{D_{inf}^- + D_{inf}^+} \tag{5}$$

Cash inflow effects of the inferior process

Increased cash inflows from selling more superior outputs

In case of excess demand for the superior output (case 1), flexibility potential established in the inferior process creates additional inflows because capacity can be reallocated to increase the sales volume of the superior output. The realization of the excess demand thereby determines the realized flexibility. Due to the reproduction property of the uniform distribution, the excess demand is uniformly distributed in $[0, D_{\text{sup}}^+]$. To obtain the level of flexibility f_{inf} of the inferior process that has to be realized to cover a distinct excess demand for the superior output, the excess demand has to be divided by $C_{\text{inf}} \cdot T$. The realized level of flexibility then is a random variable uniformly distributed in $[0; \frac{D_{\text{sup}}^+}{C_{\text{inf}} \cdot T}]$. Its density function is $u(f_{\text{inf}}) = C_{\text{inf}} T / D_{\text{sup}}^+$ (Berger 2010).

For a given level of realized flexibility f_{inf} of the inferior process, the additional capacity for the superior process is obtained by multiplying the realized flexibility with the exchange rate and the capacity of the inferior process. As capacity is only reallocated if it is required to cover excess demand, additional capacity directly turns into additional sales volume. By multiplying the additional sales volume with the profit margin of the superior output, the profit function is $p(f_{\text{inf}}) = C_{\text{inf}} T M_{\text{sup}} \cdot f_{\text{inf}}$. One has to consider that not all excess demand realizations can be covered because the flexibility potential F_{inf} is an upper boundary for f_{inf} . Larger excess demands lead to a complete realization of the flexibility potential and to the corresponding cash inflows. Equation (6) shows the expected periodic inflow increases from selling more superior outputs. The first addend refers to the demand realizations that can be covered completely. The second addend deals with the demand realizations that cannot be covered completely.

$$\begin{aligned} E_1[p(f_{\text{inf}})] &= \int_0^{F_{\text{inf}}} C_{\text{inf}} T M_{\text{sup}} f_{\text{inf}} u(f_{\text{inf}}) df_{\text{inf}} + \left(1 - \frac{C_{\text{inf}} T}{D_{\text{sup}}^+} F_{\text{inf}}\right) \cdot C_{\text{inf}} T M_{\text{sup}} \cdot F_{\text{inf}} \\ &= M_{\text{sup}} C_{\text{inf}} T \cdot F_{\text{inf}} - \frac{M_{\text{sup}} C_{\text{inf}}^2 T^2}{2 D_{\text{sup}}^+} \cdot F_{\text{inf}}^2 \end{aligned} \quad (6)$$

Reduced cash inflows from selling less inferior outputs

To derive the reduced inflows from selling less inferior outputs, we have to consider the demand distribution of both outputs. Reduced inflows result from the fact that less units of the inferior output can be produced because the capacity of the inferior process is used (in parts) for creating the superior output. This corresponds to cases 1.1 and 1.2 from Fig. 1.

In case 1.1, the demand for the inferior output exceeds the capacity of the inferior process. As the capacity of the inferior process is reduced at the same time, the remaining capacity is always smaller than the realized demand. This leads to a capacity shortage and reduced inflows. For a given level of realized flexibility f_{inf} , an amount of $f_{\text{inf}} \cdot C_{\text{inf}}$ capacity units has to be reallocated. The corresponding function for the reduced cash inflows is $o(f_{\text{inf}}) = C_{\text{inf}} M_{\text{inf}} \cdot f_{\text{inf}}$. To derive the expected inflow decreases, $o(f_{\text{inf}})$ has to be integrated over the density function $u(f_{\text{inf}})$. Analogous to the inflow increases, the highest possible inflow decreases depend on the flexibility potential F_{inf} of the inferior process. An illustration is shown in Fig. 2a.

$$\begin{aligned} E_{1.1}[o(f_{\text{inf}})] &= \int_0^{F_{\text{inf}}} C_{\text{inf}} M_{\text{inf}} f_{\text{inf}} \cdot u(f_{\text{inf}}) df_{\text{inf}} + \left(1 - \frac{C_{\text{inf}} T}{D_{\text{sup}}^+} F_{\text{inf}}\right) \cdot C_{\text{inf}} M_{\text{inf}} \cdot F_{\text{inf}} \\ &= M_{\text{inf}} C_{\text{inf}} \cdot F_{\text{inf}} - \frac{M_{\text{inf}} C_{\text{inf}}^2 T}{2 D_{\text{sup}}^+} \cdot F_{\text{inf}}^2 \end{aligned} \quad (7)$$

In case 1.2, the inferior process has free capacity because the demand for the inferior output is smaller than the capacity of the inferior process. The free capacity $k_{\text{inf}} \in \mathbb{R}_0^+$ equals the difference between the realized demand and its capacity. As the free capacity can range from 0, if the demand for the inferior output equals the capacity of the inferior process, and D_{inf}^- , if the demand realizes at the minimum demand, it is uniformly distributed in $[0; D_{\text{inf}}^-]$ with a density function of $u(k_{\text{inf}}) = 1/D_{\text{inf}}^-$.

If the reallocated capacity $f_{\text{inf}} \cdot C_{\text{inf}}$ is smaller than the free capacity of the inferior process, there is no capacity shortage for the inferior output and no cash inflow decreases occur. If the reallocated capacity exceeds the free capacity, there is a capacity shortage that causes decreased inflows. Given a distinct free capacity, the lost sales volume of the inferior output equals the difference between the reallocated capacity and the free capacity ($f_{\text{inf}} \cdot C_{\text{inf}} - k_{\text{inf}}$). The expected loss in sales volume then equals the integral of this difference over the density function of the free capacity. As only realizations between 0 and $f_{\text{inf}} \cdot C_{\text{inf}}$ are relevant, the integral is parameterized accordingly. To obtain the expected inflow decreases for a distinct level of realized flexibility f_{inf} , the expected loss in sales volume has to be multiplied by the profit margin of the inferior output.

$$E_{1.2}[o(f_{\text{inf}})] = \int_0^{f_{\text{inf}} \cdot C_{\text{inf}}} (f_{\text{inf}} \cdot C_{\text{inf}} - k_{\text{inf}}) M_{\text{inf}} \cdot u(k_{\text{inf}}) dk_{\text{inf}} = \frac{C_{\text{inf}}^2 M_{\text{inf}}}{2 D_{\text{inf}}^-} \cdot f_{\text{inf}}^2 \quad (8)$$

To fully specify the inflow decreases, another technical case distinction is necessary. If the flexibility potential of the inferior process exceeds the threshold $D_{\text{inf}}^-/C_{\text{inf}}$ (case 1.2.1, Fig.

2b), the realized flexibility f_{inf} of the inferior process can also exceed this threshold. The reallocated capacity $f_{\text{inf}} \cdot C_{\text{inf}}$ would be larger than the maximal free capacity D_{inf}^- of the inferior process and the capacity of the inferior process would be reduced below the minimum demand for the inferior output. Such a capacity reduction below the minimum demand leads to certain inflow decreases and has to be treated differently than capacity reductions where the remaining capacity is above the minimum demand, a constellation that causes uncertain inflow reductions only. If the flexibility potential is below the threshold $D_{\text{inf}}^-/C_{\text{inf}}$ (case 1.2.2, Fig. 2c), the capacity of the inferior process cannot be reduced below the minimum demand. As a result, the inflow reductions are always uncertain. As the equations for the expected inflow reductions become very complex for this case distinction, we only show them in the appendix.

To get the inflow effects of making the inferior process more flexible for a single period, the results obtained so far must be combined by weighting them with their probability of occurrence. The periodic cash inflow function is continuous and monotonically increasing with decreasing marginal inflows.

$$I_{\text{inf}}^{\text{periodic}}(F_{\text{inf}}) = Prob_{1.1} \cdot E_1[p(f_{\text{inf}})] - Prob_{1.1} \cdot E_{1.1}[o(f_{\text{inf}})] \\ + Prob_{1.2} \cdot M_{\text{inf}} \cdot \left[\begin{array}{l} \left(-\frac{C_{\text{inf}}^2}{2D_{\text{inf}}^-} \cdot F_{\text{inf}}^2 + \frac{C_{\text{inf}}^3 T}{3D_{\text{inf}}^- D_{\text{sup}}^+} \cdot F_{\text{inf}}^3 \right) \text{ for } F_{\text{inf}} \leq \frac{D_{\text{inf}}^-}{C_{\text{inf}}} \\ \left(\frac{D_{\text{inf}}^-}{2} - \frac{(D_{\text{inf}}^-)^2}{6D_{\text{sup}}^+} - C_{\text{inf}} \cdot F_{\text{inf}} + \frac{C_{\text{inf}}^2 T}{2D_{\text{sup}}^+} \cdot F_{\text{inf}}^2 \right) \text{ for } F_{\text{inf}} > \frac{D_{\text{inf}}^-}{C_{\text{inf}}} \end{array} \right] \quad (9)$$

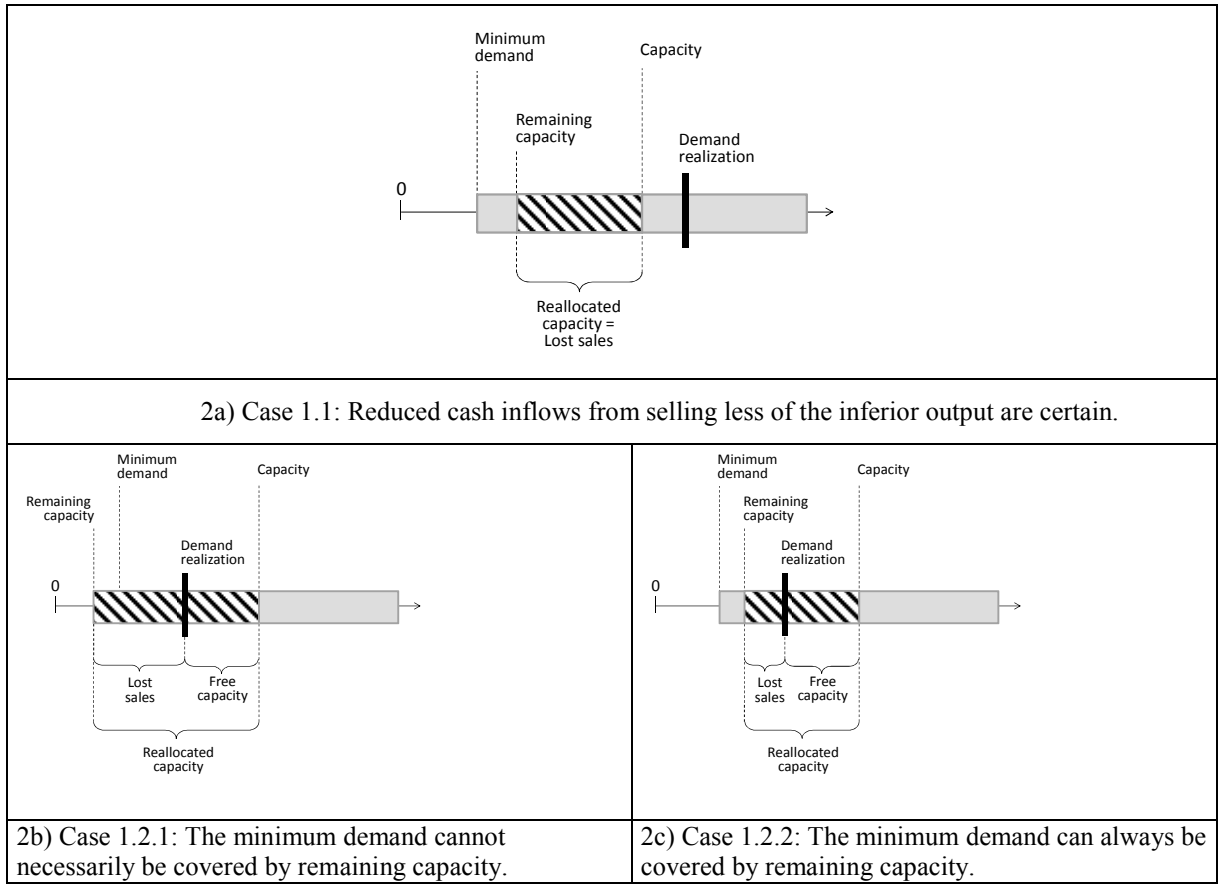


Fig. 2. Exemplary illustration for the cases 1.1 and 1.2

Cash inflow effects of the superior process

As for the superior process, we consider the case where the demand for the superior output realizes below the capacity of the superior process and the demand for the inferior output exceeds the capacity of the inferior process (case 2.1). In this case, it is reasonable to reallocate free capacity of the superior process to the inferior process. Similar to the previous cases, the demand realizations for the superior process determine the level of realized flexibility. With the superior process being more profitable, the inferior process is only supported if free capacity is available. Analogous to the inferior process, the free capacity of the superior process $k_{sup} \in \mathbb{R}_0^+$ is uniformly distributed in $[0, D_{sup}^-]$ with a density function of $u(k_{sup}) = 1/D_{sup}^-$. By dividing the free capacity by the capacity of the superior process, the maximal realized flexibility f_{sup} of the superior process can be derived, which again is uniformly distributed with a density $u(f_{sup}) = C_{sup}/D_{sup}^-$.

The product of the maximal realizable flexibility of the superior process and its capacity equals the maximal capacity of the superior process that can be reallocated. Dividing it by the exchange rate turns the reallocated into received capacity and the maximal additional capacity for the inferior process can be derived. The maximal cash flow increases

$p_{\max}(f_{\text{sup}})$ can be determined if the maximal additional capacity is multiplied with the profit margin of the inferior output and divided by the exchange rate.

$$p_{\max}(f_{\text{sup}}) = \frac{C_{\text{sup}} M_{\text{inf}}}{T} f_{\text{sup}} \quad (10)$$

Whether the maximal inflow increases are realized or not, depends on the excess demand $l_{\text{inf}} \in \mathbb{R}^+$ realization of the inferior process. Excess demand realizations below the maximal additional capacity can be covered completely. Thus, the inflow increases equal the excess demand multiplied with the profit margin of the inferior output. For excess demand realizations beyond the maximal additional capacity, the inflow increases are maximal $p_{\max}(f_{\text{sup}})$. As the density function $u(l_{\text{inf}}) = 1/D_{\text{inf}}^+$ is given due to the reproduction property of the uniform distribution, we can derive the expected inflow increases for a given level of realizable flexibility in Equation (11). The first addend equals the expected inflow increases for excess demands that can be covered completely. The second addend represents the expected inflow increases for excess demand realization beyond the maximal additional capacity.

$$\begin{aligned} E_{2.1}(p(f_{\text{sup}})) &= \int_0^{\frac{C_{\text{sup}}}{T} f_{\text{sup}}} l_{\text{inf}} M_{\text{inf}} u(l_{\text{inf}}) dl_{\text{inf}} + \left(1 - \frac{C_{\text{sup}}}{T D_{\text{inf}}^+} f_{\text{sup}}\right) p_{\max}(f_{\text{sup}}) \\ &= \frac{M_{\text{inf}} C_{\text{sup}}}{T} \cdot f_{\text{sup}} - \frac{M_{\text{inf}} C_{\text{sup}}^2}{2T^2 D_{\text{inf}}^+} \cdot f_{\text{sup}}^2 \end{aligned} \quad (11)$$

To derive the expected periodic inflows $I_{\text{sup}}^{\text{periodic}}(F_{\text{sup}})$ that result from making the superior process more flexible, we integrate the expected inflows for a given level of realized flexibility (Equation 11) over the density of the realizable flexibility and we weight the intermediate result with the corresponding probability for case 2.1. Realizable flexibilities exceeding the flexibility potential are again compressed to one value.

$$\begin{aligned} I_{\text{sup}}^{\text{periodic}}(F_{\text{sup}}) &= \text{Prob}_{2.1} \int_0^{F_{\text{sup}}} \left(\frac{M_{\text{inf}} C_{\text{sup}}}{T} \cdot f_{\text{sup}} - \frac{M_{\text{inf}} C_{\text{sup}}^2}{2T^2 D_{\text{inf}}^+} \cdot f_{\text{sup}}^2 \right) u(f_{\text{sup}}) df_{\text{sup}} \\ &\quad + \text{Prob}_{2.1} \left(1 - \frac{C_{\text{sup}}}{D_{\text{sup}}^-} F_{\text{sup}} \right) \left(\frac{M_{\text{inf}} C_{\text{sup}}}{T} \cdot F_{\text{sup}} - \frac{M_{\text{inf}} C_{\text{sup}}^2}{2T^2 D_{\text{inf}}^+} \cdot F_{\text{sup}}^2 \right) \\ &= \text{Prob}_{2.1} \frac{M_{\text{inf}} C_{\text{sup}}}{T} \cdot F_{\text{sup}} - \text{Prob}_{2.1} \left(\frac{1}{2T^2 D_{\text{inf}}^+} + \frac{1}{2D_{\text{sup}}^- T} \right) M_{\text{inf}} C_{\text{sup}}^2 \cdot F_{\text{sup}}^2 \\ &\quad + \text{Prob}_{2.1} \frac{M_{\text{inf}} C_{\text{sup}}^3}{3T^2 D_{\text{sup}}^- D_{\text{inf}}^+} \cdot F_{\text{sup}}^3 \end{aligned} \quad (12)$$

V.2.3.3 *Cash outflow effects of process flexibility*

So far, we only analyzed the cash inflow effects of process flexibility. However, making processes flexible also leads to cash outflows. Cash outflows do not only depend on the level of process flexibility, but also on other factors, namely (a) cash outflows for project overhead such as administration and coordination, and (b) process-related characteristics such as the criticality of certain process steps and the similarity of both processes. Similar to the inflows, the outflows have to be calculated for each process separately. The difference is that, for the outflows, we can basically use the same function for both processes whereas the inflows required different functions. In this section, we demonstrate the cash outflow analysis for the inferior process.

First, process flexibility itself is analyzed. The idea of enabling a process to flexibly use its capacity is in line with the concept of flexibility-by-design (Schonenberg et al. 2008). Flexibility-by-design requires that various execution alternatives – in our case: producing the own output or the output of the superior process – have to be enabled. In line with our process understanding, process flexibility further requires resources and people of the company to be flexible (Sethi and Sethi 1990). The higher the desired level of process flexibility, the more flexibility projects have to be implemented. Implementing more flexibility projects also leads to cash outflows for administration and coordination, which increase over-proportionally with the project size (Verhoef 2002). In addition, a company is likely to implement the cheapest flexibility projects first. We model the properties of the cash outflows using the function $C_{\text{inf}} \cdot F_{\text{inf}}^2$. As one can see, the outflows increase with the desired level of process flexibility and capture the project overhead as the level of process flexibility is raised by the power of two. Of course, any larger exponent would fulfill the requirement of an over-proportional course as well. We chose to use a squared function as it keeps the optimization problem analytically solvable, an approach inspired by Goyal and Netessine (2011). As for monetization, the cash outflows needed to make one capacity unit of the inferior process flexible, i.e., to enable the creation of T superior outputs, have to be incorporated. This factor highly depends on the processes at hand. In a worst-case scenario, the superior process has to be duplicated to enable the creation of the superior output on the inferior process. Although this worst case would most likely lead to prohibitively high cash outflows and, as a result, to an optimal level of process flexibility of zero, it is a reasonable starting point to calibrate the height of the cash outflows. Duplicating the superior process would lead to cash outflows that equal the initial investment of the superior process. By dividing these outflows by the capacity of the superior process and dividing the intermediate

result with the exchange rate, we get the highest possible outflows for making one capacity unit of the inferior process flexible. The corresponding parameter is called scaling factor $G_{\text{inf}} \in \mathbb{R}^+$. The cash outflows that occur in the worst case scenario for a distinct level of process flexibility are $G_{\text{inf}} \cdot C_{\text{inf}} \cdot F_{\text{inf}}^2$.

When estimating the actual cash outflows for a distinct level of process flexibility, we use process-related characteristics to reduce the cash outflows of the worst-case scenario. Obviously, only those process steps that limit the capacity of the superior process have to be incorporated in the inferior process. We call these process steps critical. The more critical steps the superior process has, the more process steps have to be supported by the inferior process and the more expensive is the establishment of a distinct level of process flexibility. Thus, the first process-related characteristic that reduces the scaling factor is criticality. The criticality is inspired by the ideas from Gebauer and Schober (2006), and defined as the relation between the number of all process steps and the number of critical process steps of the superior process:

$$\frac{\sum \text{critical steps of the superior process}}{\text{all steps of the superior process}} \quad (13)$$

The next process-related characteristic is how similar the critical process steps of the superior process are with the counterparts – if available – from the inferior process. The more similar the critical process steps and their counterparts, the less outflows occur for establishing a distinct level of process flexibility. Therefore, the similarity s (with $0 \leq s \leq 1$) between a critical process step of the superior process and its counterpart in the inferior process also reduces the scaling factor. To present an approach for determining similarity, we refer to the concept of variability introduced by Gebauer and Schober (2006). They rely on the Lorenz curve to derive the concentration of process variants (i.e., different execution paths of a process). The higher the concentration of the process variants, the lower is the need for process flexibility. As Gebauer and Schober focus on one process instead of two, this concept has to be adjusted to fit into our model. We therefore use the frequency distribution of the variants of the superior process to determine to what extent a critical process step of the superior process is already supported by the inferior process. Consider that a critical process step i has n_i different variants $v_{i,j}$. The variants of this step occur with a frequency $p(v_{i,j}) \in [0,1]$. To obtain the similarity, we introduce a decision variable $d(v_{i,j}) \in \{0,1\}$ that equals 0 if the variant $v_{i,j}$ of the critical process step i can only be produced by the inferior process after a flexibility investment and 1 if the variant can already

be produced. The decision variables are weighted with the occurrence probability of the corresponding variant and cumulated over the variants n_i :

$$s_i = \sum_{j=1}^{n_i} p(v_{i,j}) \cdot d(v_{i,j}) \quad (14)$$

When multiplying the criticality measure with the scaling factor, we get an estimate for the cash outflows by implicitly assuming that each process step is equally expensive to install. This estimate, however, does not consider that similar process steps do not create outflows. By subtracting the similarity measure from 1, we get a standardized variable that reflects the non-similarity of a critical process step, a quantity that is responsible for cash outflows. Summing up these non-similarity measures over all critical process steps weights the critical process steps with their similarity and, thus, is a reasonable estimate for adjusting the scaling factor. In the following, we use the process factor r_{inf} that adjusts the scaling factor not only for non-critical process steps, but that also incorporates the similarity of both processes.

$$r_{\text{inf}} = \frac{\sum_{i \in \text{critical process steps}} (1 - s_i)}{\text{all steps of the superior process}} \quad (15)$$

By multiplying the process factor and the scaling factor, the cash outflows for making a single capacity unit of the inferior process flexible can be estimated as the scaling factor, defined as the worst-case outflows for a given level of process flexibility, is adjusted based on the process characteristics that naturally support process flexibility. To obtain an estimate for the cash outflows, the product of the process factor and the scaling factor has to be multiplied with $C_{\text{inf}} \cdot F_{\text{inf}}^2$.

$$C(F_{\text{inf}}) = G_{\text{inf}} \cdot r_{\text{inf}} \cdot C_{\text{inf}} \cdot F_{\text{inf}}^2 \quad (16)$$

To derive the outflows of the superior process, the same approach can be applied. The scaling factor can be obtained by dividing the initial investment of the inferior process through its capacity and by multiplying the intermediate result with the exchange rate. As for the criticality, the critical steps of the inferior process are decisive instead of the critical steps of the superior process. With similarity being a double-sided measure, the approach applied here can directly be copied.

V.2.3.4 Solving the optimization model

To find the optimal levels of flexibility for the superior and the inferior process, we calculate the risk-adjusted expected NPV. As the cash outflows occur at the beginning of the planning horizon, they need not be discounted. The risk-adjusted expected NPV of the cash inflows

can be derived by the discounting of the expected additional inflows per period. For a constant risk-adjusted discount rate $i \in \mathbb{R}^+$ and a planning horizon of $N \in \mathbb{N}$ periods, the discount factor $\delta \in \mathbb{R}^+$ can be calculated by the formula of the partial sum of a geometric sequence.

$$\delta = \frac{1 - \left(\frac{1}{1+i}\right)^{N+1}}{\frac{i}{1+i}} \quad (17)$$

The optimum of the objective function is characterized by the equality of the marginal inflows and the marginal outflows. As the marginal outflows are strictly increasing and strictly convex and the marginal cash inflows are strictly decreasing, there is exactly one optimum, i.e., a global maximum. For the optimal flexibility of the inferior process, it has to be taken into consideration that there are different objective functions due to the technical case distinction we had to introduce for case 1.2. Whether the optimum is located in the first or in the second definition range cannot be forecasted without knowing concrete values for the model parameters. Thus, two optimality conditions must be derived. The detailed derivations are depicted in the appendix.

For $F_{\text{inf}} \leq \frac{D_{\text{inf}}^-}{C_{\text{inf}}}$: $F_{\text{inf}}^* =$

$$\begin{aligned} & \frac{\frac{M_{\text{sup}} C_{\text{inf}} T^2}{D_{\text{sup}}^+} \text{Prob}_1 + \frac{2G_{\text{inf}} r_{\text{inf}}}{\delta} + \frac{C_{\text{inf}} M_{\text{inf}}}{D_{\text{inf}}^-} \text{Prob}_{1.2} - \frac{M_{\text{inf}} C_{\text{inf}} T}{D_{\text{sup}}^+} \text{Prob}_{1.1}}{\frac{2C_{\text{inf}}^2 T M_{\text{inf}} \text{Prob}_{1.2}}{D_{\text{inf}}^- D_{\text{sup}}^+}} \\ & - \sqrt{\left(-\frac{M_{\text{sup}} C_{\text{inf}} T^2}{D_{\text{sup}}^+} \text{Prob}_1 - \frac{2G_{\text{inf}} r_{\text{inf}}}{\delta} - \frac{C_{\text{inf}} M_{\text{inf}}}{D_{\text{inf}}^-} \text{Prob}_{1.2} + \frac{M_{\text{inf}} C_{\text{inf}} T}{D_{\text{sup}}^+} \text{Prob}_{1.1}\right)^2 + \text{Prob}_{1.2} \frac{4C_{\text{inf}}^2 T M_{\text{inf}}}{D_{\text{inf}}^- D_{\text{sup}}^+} \cdot (\text{Prob}_1 M_{\text{sup}} T - \text{Prob}_{1.1} M_{\text{inf}})}{\frac{2C_{\text{inf}}^2 T M_{\text{inf}} \text{Prob}_{1.2}}{D_{\text{inf}}^- D_{\text{sup}}^+}} \end{aligned} \quad (18a)$$

$$\text{For } F_{\text{inf}} > \frac{D_{\text{inf}}^-}{C_{\text{inf}}}: F_{\text{inf}}^* = \frac{\text{Prob}_1 (M_{\text{sup}} T - M_{\text{inf}})}{\frac{C_{\text{inf}} T}{D_{\text{sup}}^+} \cdot \text{Prob}_1 (M_{\text{sup}} T - M_{\text{inf}}) + \frac{2G_{\text{inf}} r_{\text{inf}}}{\delta}} \quad (18b)$$

$$F_{\text{sup}}^* = \frac{\frac{C_{\text{sup}}}{T D_{\text{inf}}^+} + \frac{C_{\text{sup}}}{D_{\text{sup}}^-} + \frac{2TG_{\text{sup}} r_{\text{sup}}}{\text{Prob}_{2.1} \delta M_{\text{inf}}} - \sqrt{\left(-\frac{C_{\text{sup}}}{T D_{\text{inf}}^+} - \frac{C_{\text{sup}}}{D_{\text{sup}}^-} - \frac{2TG_{\text{sup}} r_{\text{sup}}}{\text{Prob}_{2.1} \delta M_{\text{inf}}}\right)^2 + 4 \frac{C_{\text{sup}}^2}{T D_{\text{sup}}^- D_{\text{inf}}^+}}{2 \frac{C_{\text{sup}}^2}{T D_{\text{sup}}^- D_{\text{inf}}^+}} \quad (19)$$

V.2.4 Real-world application in the service sector

In our previous work (Afflerbach et al. 2013), we applied a less developed version of the optimization model to the wafer production processes of a company from the semiconductor industry. In that case, process flexibility was achieved by investing 3,000,000 EUR in a multi-purpose machine whose capacity could be used to produce a basic and a sophisticated wafer on the inferior process. We showed that the investment in process flexibility was reasonable. By comparing the investment outflows with the sales effects, we also found that a machine with a smaller capacity would have been sufficient to cover the forecast demand and would have implied cost savings of 600,000 EUR.

As we aimed at developing a model for process flexibility that fits several application domains, we now demonstrate how to apply the model in the service sector. Such a demonstration is worthwhile because process flexibility has to be achieved by different projects in the service sector. While, in the manufacturing context, flexibility can be achieved by multi-purpose machines, in the service sector it depends much more on people and their skills. We report on how we determined the optimal levels of flexibility for the coverage switching processes of a financial service provider that intended to achieve process flexibility by multi-skilling. We first provide information on the case context and then determine the optimal levels of process flexibility using the optimization model.

The case company is a leading insurance broker pool from the German-speaking countries that supports insurance brokers in their daily business by taking over back-office activities (e.g., communication with insurance companies or administrating contracts). In return, the case company charges proportional commissions. As typical for a service provider, the case company has a predisposition for investing in process flexibility as services cannot be stored. This property makes it impossible to cover excess demand by inventory buffers and, thus, requires flexibility to be implemented in the processes themselves.

Coverage switching processes adhere to the following blueprint: In case an insurance broker acquires a new customer, the customer's current insurance situation is analyzed for potential improvements in premiums and risk coverage. It is important to find out whether the customer's current contracts contain special conditions and whether her risk situation disables her to be served by a potentially better insurance. For example, a homeowner's insurance cannot be switched if the respective residential building has aged pipes. In fact, most insurers reject a customer if the pipes have reached a certain age as the risk for such pipes to break is considered very high. If a current contract can be favorably switched, the

case company must update the information about relevant risk factors, a task that is required by the new insurer for accepting the customer. Finally, the department has to cancel the current contract and to buy the new contract.

The case company operates two coverage switching processes, one for homeowner's insurances and another for accident insurances. The process that deals with homeowner's insurances is the inferior process. As each insurance type requires specific in-depth knowledge, both processes are executed by separate employees. In order to be able to react more flexibly to fluctuating demand, the case company intended to train some employees so that they can conduct the coverage switching process for both insurance products. We applied the optimization model to determine the optimal levels of process flexibility and, on that foundation, derive the optimal skilling profile of the involved employees.

The input data about the capacity strategy, the process factors, and the demand distribution (including the demand boundaries) were provided by the head of the department responsible for the coverage switching process (Tab. 1). The case company sets its capacities to equal the expected demands. As both processes have the same demand distribution, they have the same capacity. Regarding the profit margins, service times, and training costs, the coverage switching process is more complex for the homeowner's insurance. The reason is that a homeowner's insurance is a bundle of fire, windstorm, glass breakage, and burst pipe insurances, a fact that requires more complex analyses than an accident insurance. The higher complexity leads to longer service times, lower profit margins, and higher training costs. Each process was executed by two employees. Considering the different service times, we were surprised that both processes had identical capacities and were executed by the same number of employees. The reason was that the employees of the process for accident insurances were not only responsible for the coverage switching process, but also for other processes. The case company typically used a planning horizon of $n = 7$ years and a yearly risk-adjusted interest rate $i = 0.04$ for investment decisions.

Parameters	Homeowner's insurance (inferior process)	Accident insurance (superior process)
Capacity ($C_{inf/sup}$)	200 executions p.m.*	200 executions p.m.
Expected demand ($X_{inf/sup}$)	200 executions p.m.	200 executions p.m.
Upper boundary for the demand ($C_{inf/sup} + D_{inf/sup}^+$)	250 executions p.m.	250 executions p.m.
Lower boundary for the demand ($C_{inf/sup} - D_{inf/sup}^-$)	150 executions p.m.	150 executions p.m.
Profit margin ($M_{inf/sup}$)	40 EUR per execution	100 EUR per execution
Service time	1 hour per transaction	0.5 hours per transaction
Number of employees staffed	2 employees	2 employees
Training costs	15,000 EUR per employee	10,000 EUR per employee

Table 1: Input data (* p.m. = per month)

Whereas the values for most input parameters could be observed directly, the exchange rate, the cash outflows, and the probabilities of occurrence for the cases introduced in Fig. 1 had to be assessed separately. The exchange rate results from the relationship between the service times of both processes. It equals $T = 1 \text{ h}/0.5 \text{ h} = 2$. As for the cash outflows, we had to determine the process and the scaling factor of both processes. Taking the process for homeowner's insurances as example, training both employees leads to outflows of 30,000 EUR and to a flexibility potential of $F_{inf} = 100 \%$. Based on these considerations, we can calculate the combined process and scaling factor $G_{inf} \cdot r_{inf} = 150 \text{ EUR}$ based on the outflow function (Equation 16). For the process that deals with accident insurances, the combined process and scaling factor is $G_{sup} \cdot r_{sup} = 100 \text{ EUR}$. As the demand scatters symmetrically around the capacities, the probabilities of the cases introduced in Fig. 1 equal 50% each. As in our previous case from the semi-conductor industry, the input parameters could be assessed easily.

Having finished the data collection, we applied the optimization model to identify the optimal levels of process flexibility. In the case at hand, process flexibility could not be treated as a continuous variable because of the small number of employees per process. The case company could only establish 50 % or 100 % flexibility for each process. Thus, we did not apply Equations (18a), (18b), and (19) to determine the continuous optima. Instead, we used the objective function of the optimization model to calculate the risk-adjusted expected NPV of each decision alternative (Tab. 2). The results indicate that, in the case at hand, investments in process flexibility are always more profitable than leaving the status quo unchanged. Multi-skilling one employee per process leads to an economically optimal

solution and a risk-adjusted expected NPV of about 82,000 EUR. To provide guidance for larger departments, we also show the exact continuous optima at the end of this section.

$F_{\text{inf}}/F_{\text{sup}}$	0 %	50 %	100 %
0 %	0 EUR	14,778 EUR	4,778 EUR
50 %	67,078 EUR	81,857 EUR (*)	71,857 EUR
100 %	52,078 EUR	66,857 EUR	56,857 EUR

Table 2: Risk-adjusted expected NPVs for the different decision alternatives

By applying the optimization model to the case company, we also gathered novel insights into the relationships among the input parameters. We found that the maximum demand deviation serves as an upper boundary for the flexibility potential. Regarding the process for homeowner's insurances, a flexibility potential of 12.5 % and beyond causes the same cash inflow effects. The reason is that the case company can cover the maximum demand with that level of process flexibility. As this level of process flexibility is below the threshold of the case distinction (i.e., $D_{\text{inf}}^-/C_{\text{inf}} = 25\%$), the expected additional inflows for a process flexibility of 50 % and 100 % can be calculated by inserting 12.5 % into Equation (7). The differences in the risk-adjusted expected NPV result from the outflows for training different numbers of employees. The same argumentation holds true for the process that deals with accident insurances. Here, the critical level of process flexibility is 25 % due to the specific exchange rate.

For processes with a larger number of employees, where process flexibility can be treated as a continuous variable, Equations (18a), (18b), and (19) can be applied to determine the optimal levels of process flexibility. With the given parameter values, the coverage switching process for homeowner's insurances would amount to 12.43 % of process flexibility. This value is very close to the process flexibility that is required to completely support the process for accident insurances. Regarding the process for accident insurances, the optimization model determines 22.3 % as optimal level of process flexibility. Again, this result is plausible as it is very close to the flexibility value that enables a complete support of the other process. In this case, the optimal results are located close to their reasonable maxima, a circumstance that shows that flexibility is relatively cheap and that the case company greatly benefits from respective multi-skilling investments.

V.2.5 Conclusion

In this paper, we presented an optimization model to determine the optimal level of process flexibility, which we define as the fraction of the capacity that can be reallocated from one process to another. The model meets the shortcomings of previously proposed approaches regarding the economic valuation of process flexibility as it puts particular emphasis on the positive economic effects of process flexibility. The model relies on risky demand as well as further process characteristics such as criticality, similarity, and variability. By considering the cash effects of process flexibility, a multi-period planning horizon, and a risk-adjusted interest rate, the model complies with the principles of value-based BPM. Finally, we demonstrated the model's applicability using the coverage switching processes of an insurance broker pool provider as example.

The optimization model is beset with the following limitations that should be subject to further research: First, in line with our objectives, we made some simplifying assumptions, i.e., the focus on two processes as well as on an independent and uniformly distributed demand. This setting, on the other hand, enabled us to structure the optimization problem at hand, to identify relevant parameters and their economic effects as well as to analytically determine an optimal level of process flexibility. The optimization model could also be easily applied in industry and helped extend industrial decision-making capabilities. However, further research should explore which assumptions can be relaxed and how the insights gained so far can be generalized. For example, the optimization model should be extended to more than two processes and different demand distributions. Second, whilst paying much attention to the positive economic effects of process flexibility, we modeled the cash outflows in a rather coarse-grained manner. Future research should therefore strive for a more sophisticated modeling that also includes further process characteristics that drive process flexibility.

V.2.6 References

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V.2.7 Appendix

V.2.7.1 *Derivation of the expected increases in cash inflows of making the inferior process more flexible $E_1[p(f_{inf})]$:*

$$\begin{aligned}
E_1[p(f_{inf})] &= \int_0^F C_{inf} T M_{sup} \cdot f_{inf} \cdot u(f_{inf}) df_{inf} + \left(1 - \frac{C_{inf} T}{D_{sup}^+} F_{inf}\right) \cdot C_{inf} T M_{sup} F_{inf} \\
&= \int_0^F C_{inf} T M_{sup} \cdot \frac{C_{inf} T}{D_{sup}^+} f_{inf} df_{inf} + \left(1 - \frac{C_{inf} T}{D_{sup}^+} F_{inf}\right) \cdot C_{inf} T M_{sup} F_{inf} = \\
&= \frac{M_{sup} C_{inf}^2 T^2}{D_{sup}^+} \int_0^F f_{inf} df_{inf} + \left(1 - \frac{C_{inf} T}{D_{sup}^+} F_{inf}\right) \cdot C_{inf} T M_{sup} F_{inf} \\
&= \frac{M_{sup} C_{inf}^2 T^2}{D_{sup}^+} \left[\frac{f_{inf}^2}{2}\right]_0^F + \left(1 - \frac{C_{inf} T}{D_{sup}^+} F_{inf}\right) \cdot C_{inf} T M_{sup} F_{inf} \\
&= \frac{M_{sup} C_{inf}^2 T^2}{2 D_{sup}^+} \cdot F_{inf}^2 + M_{sup} C_{inf} T F_{inf} - \frac{M_{sup} C_{inf}^2 T^2}{D_{sup}^+} \cdot F_{inf}^2 \\
&= M_{sup} C_{inf} T F_{inf} - \frac{M_{sup} C_{inf}^2 T^2}{2 D_{sup}^+} \cdot F_{inf}^2
\end{aligned} \tag{1}$$

V.2.7.2 *Derivation of the expected decreases in cash inflows of making the inferior process more flexible in case of excess demand for the inferior process $E_{2.1}[o(f_{inf})]$:*

$$\begin{aligned}
E_{2.1}[o(f_{inf})] &= \int_0^F C_{inf} M_{inf} \cdot f_{inf} \cdot u(f_{inf}) df_{inf} + \left(1 - \frac{C_{inf} T}{D_{sup}^+} F_{inf}\right) \cdot C_{inf} M_{inf} F_{inf} \\
&= \int_0^F C_{inf} M_{inf} \cdot \frac{C_{inf} T}{D_{sup}^+} f_{inf} df_{inf} + \left(1 - \frac{C_{inf} T}{D_{sup}^+} F_{inf}\right) \cdot C_{inf} M_{inf} F_{inf} = \\
&= \frac{M_{inf} C_{inf}^2 T}{D_{sup}^+} \int_0^F f_{inf} df_{inf} + \left(1 - \frac{C_{inf} T}{D_{sup}^+} F_{inf}\right) \cdot C_{inf} M_{inf} F_{inf} \\
&= \frac{M_{inf} C_{inf}^2 T}{D_{sup}^+} \left[\frac{f_{inf}^2}{2}\right]_0^F + \left(1 - \frac{C_{inf} T}{D_{sup}^+} F_{inf}\right) \cdot C_{inf} M_{inf} F_{inf} \\
&= \frac{M_{inf} C_{inf}^2 T}{2 D_{sup}^+} \cdot F_{inf}^2 + M_{inf} C_{inf} T F_{inf} - \frac{M_{inf} C_{inf}^2 T}{D_{sup}^+} \cdot F_{inf}^2 \\
&= M_{inf} C_{inf} T F_{inf} - \frac{M_{inf} C_{inf}^2 T}{2 D_{sup}^+} \cdot F_{inf}^2
\end{aligned} \tag{2}$$

V.2.7.3 *Derivation of the expected decreases in cash inflows of making the inferior process more flexible in case of a demand shortage for the inferior process given a level of realized flexibility $E_{1.2}[o(f_{inf})]$:*

$$\begin{aligned}
 E_{1.2}[o(f_{inf})] &= \int_0^{C_{inf}f_{inf}} (C_{inf}f_{inf} - k_{inf}) \cdot M_{inf} \cdot u(k_{inf}) dk_{inf} \\
 &= \int_0^{C_{inf}f_{inf}} (C_{inf}f_{inf} - k_{inf}) \cdot M_{inf} \cdot \frac{1}{D_{inf}^-} dk_{inf} \\
 &= \frac{M_{inf}}{D_{inf}^-} \int_0^{C_{inf}f_{inf}} (C_{inf}f_{inf} - k_{inf}) \cdot dk_{inf} = \frac{M_{inf}}{D_{inf}^-} \left[C_{inf}f_{inf}k_{inf} - \frac{k_{inf}^2}{2} \right]_0^{C_{inf}f_{inf}} \\
 &= \frac{C_{inf}^2 M_{inf}}{2 D_{inf}^-} f_{inf}^2
 \end{aligned} \tag{3}$$

As already explained, an additional case analysis is necessary to fully specify the cash inflow decreases. If the flexibility potential for the inferior process exceeds $\frac{D_{inf}^-}{C_{inf}}$ (Case 1.2.2), the realized process flexibility of the inferior process f_{inf} can obviously also exceed this threshold. Consequently, the reallocated capacity $f_{inf} \cdot C_{inf}$ would then be larger than the maximal free capacity D_{inf}^- of the inferior process. In other words, the capacity of the inferior process would be reduced below the minimum demand. Clearly, the capacity reduction beyond the minimum demand lead to certain cash inflow reductions and have to be treated differently from capacity reductions up to the minimum demand which leads to uncertain cash inflow reductions. If the flexibility potential is smaller than $\frac{D_{inf}^-}{C_{inf}}$ (Case 1.2.1), the capacity of the inferior process is definitely not reduced below the minimum demand. As a consequence, the cash inflow reductions are always uncertain. A different treatment for realized process flexibilities is not mandatory.

First, we analyze those levels of the realized flexibility that are smaller than the threshold (Case 1.2.2). To obtain the expected cash inflow decreases, the function $E_{1.2}[o(f_{inf})]$ (the expected decreases in cash inflows given a realized level of flexibility of the inferior process f_{inf}) is integrated over the density function of the flexibility of the inferior process. This covers all excess demand realizations that can be covered by the chosen level of flexibility. Again, larger realizations are considered as well.

$$\begin{aligned}
E_{1.2.1}[o(f_{\text{inf}})] &= \int_0^{F_{\text{inf}}} E_{1.2}[o(f_{\text{inf}})] \cdot u(f_{\text{inf}}) df_{\text{inf}} + \left(1 - \frac{C_{\text{inf}}T}{D_{\text{sup}}^+} F_{\text{inf}}\right) \cdot E_{1.2}[o(f_{\text{inf}} = F_{\text{inf}})] \\
&= \int_0^{F_{\text{inf}}} \frac{C_{\text{inf}}^2 M_{\text{inf}}}{2 D_{\text{inf}}^-} \cdot \frac{C_{\text{inf}} \cdot T}{D_{\text{sup}}^+} f_{\text{inf}}^2 df_{\text{inf}} + \left(1 - \frac{C_{\text{inf}}T}{D_{\text{sup}}^+} F_{\text{inf}}\right) \cdot \frac{C_{\text{inf}}^2 M_{\text{inf}}}{2 D_{\text{inf}}^-} F_{\text{inf}}^2 \\
&= \frac{C_{\text{inf}}^3 T M_{\text{inf}}}{2 D_{\text{inf}}^- D_{\text{sup}}^+} \int_0^{F_{\text{inf}}} f_{\text{inf}}^2 df_{\text{inf}} + \left(1 - \frac{C_{\text{inf}}T}{D_{\text{sup}}^+} F_{\text{inf}}\right) \cdot \frac{C_{\text{inf}}^2 M_{\text{inf}}}{2 D_{\text{inf}}^-} F_{\text{inf}}^2 \\
&= \frac{C_{\text{inf}}^3 T M_{\text{inf}}}{2 D_{\text{inf}}^- D_{\text{sup}}^+} \left[\frac{f_{\text{inf}}^3}{3} \right]_0^{F_{\text{inf}}} F_{\text{inf}} + \left(1 - \frac{C_{\text{inf}}T}{D_{\text{sup}}^+} F_{\text{inf}}\right) \cdot \frac{C_{\text{inf}}^2 M_{\text{inf}}}{2 D_{\text{inf}}^-} F_{\text{inf}}^2 \\
&= \frac{C_{\text{inf}}^3 T M_{\text{inf}}}{6 D_{\text{inf}}^- D_{\text{sup}}^+} F_{\text{inf}}^3 + \frac{C_{\text{inf}}^2 M_{\text{inf}}}{2 D_{\text{inf}}^-} F_{\text{inf}}^2 - \frac{C_{\text{inf}}^3 T M_{\text{inf}}}{2 D_{\text{inf}}^- D_{\text{sup}}^+} F_{\text{inf}}^3 \\
&= \frac{C_{\text{inf}}^2 M_{\text{inf}}}{2 D_{\text{inf}}^-} F_{\text{inf}}^2 - \frac{C_{\text{inf}}^3 T M_{\text{inf}}}{3 D_{\text{inf}}^- D_{\text{sup}}^+} F_{\text{inf}}^3
\end{aligned} \tag{4}$$

Second, we analyze those levels of flexibility potentials of the inferior process that exceed the threshold (Case 1.2.2). As already stated, levels of realized flexibility of the inferior process below and above the separating threshold have to be treated differently. The expected cash inflow decreases are a combination of the formulas derived so far. For levels of realized flexibility of the inferior process smaller than the threshold, the decreases of the cash inflows are uncertain and function (4) can be applied. For flexibility realizations larger than the threshold, the additional capacity reductions beyond the minimum demand lead to certain decreases of the cash inflows from the sales of the inferior output. Therefore, formula (2) can be used because this equation considers certain reductions of cash inflows as well. The only difference is that formula (2) does not consider free capacity because it just does not occur in cases of excess demand for the superior process. As the free capacity does not decrease the cash inflows, we have to adjust formula (2) to fit it to the case of shortage demand. The expected free capacity for levels of realized flexibility of the inferior process exceeding the threshold is given by the uniform distribution of the free capacity and equals $\frac{1}{2u(k_{\text{inf}})} = \frac{D_{\text{inf}}^-}{2}$. In terms of expected values, the reductions of the cash inflows are certain after an adjustment of $\frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}}$. Therefore, the expected reduction of the cash inflows for levels of flexibility of the inferior process exceeding $\frac{D_{\text{inf}}^-}{C_{\text{inf}}}$ equal:

$$\begin{aligned}
E_{1.2.2}[o(f_{\text{inf}})] &= \int_0^{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}} E_{1.2}[o(f_{\text{inf}})] \cdot u(f_{\text{inf}}) df_{\text{inf}} + \int_{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}}^{F_{\text{inf}}} \left(C_{\text{inf}} M_{\text{inf}} f_{\text{inf}} - \frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}} \right) \cdot u(f_{\text{inf}}) df_{\text{inf}} \\
&+ \left(1 - \frac{C_{\text{inf}} T}{D_{\text{sup}}^+} F_{\text{inf}} \right) \cdot \left(C_{\text{inf}} M_{\text{inf}} F_{\text{inf}} - \frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}} \right) \\
&= \int_0^{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}} \frac{C_{\text{inf}}^2 M_{\text{inf}}}{2D_{\text{inf}}^-} \cdot \frac{C_{\text{inf}} T}{D_{\text{sup}}^+} f_{\text{inf}}^2 df_{\text{inf}} + \int_{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}}^{F_{\text{inf}}} \left(C_{\text{inf}} M_{\text{inf}} f_{\text{inf}} - \frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}} \right) \\
&\cdot \frac{C_{\text{inf}} T}{D_{\text{sup}}^+} df_{\text{inf}} + \left(1 - \frac{C_{\text{inf}} T}{D_{\text{sup}}^+} F_{\text{inf}} \right) \cdot \left(C_{\text{inf}} M_{\text{inf}} F_{\text{inf}} - \frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}} \right) \\
&= \frac{C_{\text{inf}}^3 T M_{\text{inf}}}{2D_{\text{inf}}^- D_{\text{sup}}^+} \int_0^{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}} f_{\text{inf}}^2 \cdot df_{\text{inf}} + \frac{M_{\text{inf}} C_{\text{inf}}^2 T}{D_{\text{sup}}^+} \int_{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}}^{F_{\text{inf}}} f_{\text{inf}} df_{\text{inf}} \\
&- \frac{D_{\text{inf}}^- C_{\text{inf}} T \cdot M_{\text{inf}}}{2D_{\text{sup}}^+} \int_{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}}^{F_{\text{inf}}} df_{\text{inf}} + \left(1 - \frac{C_{\text{inf}} T}{D_{\text{sup}}^+} F_{\text{inf}} \right) \cdot \left(C_{\text{inf}} M_{\text{inf}} F_{\text{inf}} - \frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}} \right) \tag{5} \\
&= \frac{C_{\text{inf}}^3 T M_{\text{inf}}}{2D_{\text{inf}}^- D_{\text{sup}}^+} \left[\frac{f_{\text{inf}}^3}{3} \right]_{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}}^{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}} + \frac{C_{\text{inf}}^2 T M_{\text{inf}}}{D_{\text{sup}}^+} \left[\frac{f_{\text{inf}}^2}{2} \right]_{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}}^{F_{\text{inf}}} - \frac{D_{\text{inf}}^- C_{\text{inf}} T \cdot M_{\text{inf}}}{2D_{\text{sup}}^+} \left[f_{\text{inf}} \right]_{\frac{D_{\text{inf}}^-}{C_{\text{inf}}}}^{F_{\text{inf}}} \\
&+ \left(1 - \frac{C_{\text{inf}} T}{D_{\text{sup}}^+} F_{\text{inf}} \right) \cdot \left(C_{\text{inf}} M_{\text{inf}} F_{\text{inf}} - \frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}} \right) \\
&= \frac{(D_{\text{inf}}^-)^2 T}{6D_{\text{sup}}^+} \cdot M_{\text{inf}} + \frac{M_{\text{inf}} C_{\text{inf}}^2 T}{2D_{\text{sup}}^+} \cdot F_{\text{inf}}^2 - \frac{(D_{\text{inf}}^-)^2 T}{2D_{\text{sup}}^+} \cdot M_{\text{inf}} - \frac{D_{\text{inf}}^- C_{\text{inf}} T \cdot M_{\text{inf}}}{2D_{\text{sup}}^+} F_{\text{inf}} \\
&+ \frac{(D_{\text{inf}}^-)^2 T}{2D_{\text{sup}}^+} \cdot M_{\text{inf}} + C_{\text{inf}} M_{\text{inf}} F_{\text{inf}} - \frac{M_{\text{inf}} C_{\text{inf}}^2 T}{D_{\text{sup}}^+} \cdot F_{\text{inf}}^2 + \frac{D_{\text{inf}}^- C_{\text{inf}} T \cdot M_{\text{inf}}}{2D_{\text{sup}}^+} F_{\text{inf}} \\
&- \frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}} = -\frac{D_{\text{inf}}^-}{2} \cdot M_{\text{inf}} + \frac{(D_{\text{inf}}^-)^2 T}{6D_{\text{sup}}^+} \cdot M_{\text{inf}} + C_{\text{inf}} M_{\text{inf}} F_{\text{inf}} - \frac{M_{\text{inf}} C_{\text{inf}}^2 T}{2D_{\text{sup}}^+} \cdot F_{\text{inf}}^2
\end{aligned}$$

V.2.7.4 *Derivation of the expected increases of the cash inflows of the inferior process by making the superior process more flexible given a level of realizable flexibilization $E_{2.1}(p(f_{sup}))$:*

$$\begin{aligned}
E_{2.1}(p(f_{sup})) &= \int_0^{\frac{C_{sup}}{T}f_{sup}} l_{inf} \cdot M_{inf} u(l_{inf}) dl_{inf} + \left(1 - \frac{C_{sup}}{TD_{inf}^+} f_{sup}\right) p(f_{sup}) \\
&= \frac{M_{inf}}{D_{inf}^+} \int_0^{\frac{C_{sup}}{T}f_{sup}} l_{inf} dl_{inf} + \left(1 - \frac{C_{sup}}{TD_{inf}^+} f_{sup}\right) \frac{C_{sup}M_{inf}}{T} f_{sup} \\
&= \frac{M_{inf}}{D_{inf}^+} \left[\frac{l_{inf}^2}{2} \right]_0^{\frac{C_{sup}}{T}f_{sup}} \frac{C_{sup}}{T} f_{sup} + \left(1 - \frac{C_{sup}}{TD_{inf}^+} f_{sup}\right) \frac{C_{sup}M_{inf}}{T} f_{sup} \\
&= \frac{C_{sup}^2 M_{inf}}{2T^2 D_{inf}^+} f_{sup}^2 + \frac{C_{sup}M_{inf}}{T} f_{sup} - \frac{C_{sup}^2 M_{inf}}{T^2 D_{inf}^+} f_{sup}^2 \\
&= \frac{C_{sup}M_{inf}}{T} f_{sup} - \frac{C_{sup}^2 M_{inf}}{2T^2 D_{inf}^+} f_{sup}^2
\end{aligned} \tag{6}$$

V.2.7.5 *Derivation of the periodic increases of cash inflows of the inferior process by making the superior process more flexible given a level flexibility potential $I_{sup}^{periodic}(F_{sup})$:*

$$\begin{aligned}
I_{sup}^{periodic}(F_{sup}) &= Prob_{2.1} \left[\int_0^{F_{sup}} \left(\frac{C_{sup}M_{inf}}{T} f_{sup} - \frac{C_{sup}^2 M_{inf}}{2T^2 D_{inf}^+} f_{sup}^2 \right) u(f_{sup}) df_{sup} \right. \\
&\quad \left. + \left(1 - \frac{C_{sup}}{D_{sup}^-} F_{sup}\right) \left(\frac{C_{sup}M_{inf}}{T} F_{sup} - \frac{C_{sup}^2 M_{inf}}{2T^2 D_{inf}^+} F_{sup}^2 \right) \right] \\
&= Prob_{2.1} \left[\frac{C_{sup}M_{inf}}{D_{sup}^- T} \int_0^{F_{sup}} f_{sup} df_{sup} - \frac{C_{sup}^3 M_{inf}}{2T^2 D_{sup}^- D_{inf}^+} \int_0^{F_{sup}} f_{sup}^2 df_{sup} \right. \\
&\quad \left. + \left(1 - \frac{C_{sup}}{D_{sup}^-} F_{sup}\right) \left(\frac{C_{sup}M_{inf}}{T} F_{sup} - \frac{C_{sup}^2 M_{inf}}{2T^2 D_{inf}^+} F_{sup}^2 \right) \right] \\
&= Prob_{2.1} \left[\frac{C_{sup}^2 M_{inf}}{D_{sup}^- T} \left[\frac{f_{sup}^2}{2} \right]_0^{F_{sup}} F_{sup} - \frac{C_{sup}^3 M_{inf}}{2T^2 D_{sup}^- D_{inf}^+} \left[\frac{f_{sup}^3}{3} \right]_0^{F_{sup}} F_{sup} \right. \\
&\quad \left. + \left(1 - \frac{C_{sup}}{D_{sup}^-} F_{sup}\right) \left(\frac{C_{sup}M_{inf}}{T} F_{sup} - \frac{C_{sup}^2 M_{inf}}{2T^2 D_{inf}^+} F_{sup}^2 \right) \right] \\
&= Prob_{2.1} \left[\frac{C_{sup}^2 M_{inf}}{2TD_{sup}^-} F_{sup}^2 - \frac{C_{sup}^3 M_{inf}}{6T^2 D_{sup}^- D_{inf}^+} F_{sup}^3 + \frac{C_{sup}M_{inf}}{T} F_{sup} - \frac{C_{sup}^2 M_{inf}}{2T^2 D_{inf}^+} F_{sup}^2 \right. \\
&\quad \left. - \frac{C_{sup}^2 M_{inf}}{D_{sup}^- T} F_{sup}^2 + \frac{C_{sup}^3 M_{inf}}{2T^2 D_{sup}^- D_{inf}^+} F_{sup}^3 \right] \\
&= Prob_{2.1} \left[\frac{C_{sup}M_{inf}}{T} F_{sup} - \frac{C_{sup}^2 M_{inf}}{2T^2 D_{inf}^+} F_{sup}^2 - \frac{C_{sup}^2 M_{inf}}{2TD_{sup}^-} F_{sup}^2 + \frac{C_{sup}^3 M_{inf}}{3T^2 D_{sup}^- D_{inf}^+} F_{sup}^3 \right]
\end{aligned} \tag{7}$$

V.2.7.6 Derivations of the optimal levels of flexibility potentials

Optimal flexibility potential of the inferior process

For the derivation of the optimal level of flexibility potential of the inferior process, the objective function of the investment has to be determined first. Therefore, the corresponding periodic cash inflows have to be multiplied with the discount factor to obtain the risk adjusted present value from the cash inflows $I_{\text{inf}}(F_{\text{inf}})$. From the intermediate result, the cash outflows are subtracted to determine the risk adjusted net present value of a flexibility potential. The objective function can then be derived with respect to the flexibility potential. By setting the first derivative equal to zero and resolving the equation with respect to the flexibility potential of the inferior process. Because of the case distinction, this procedure has to be executed twice.

$$\begin{aligned}
 \text{For } F_{\text{inf}} \leq \frac{D_{\text{inf}}^-}{C_{\text{inf}}} : & \frac{\partial \delta I_{\text{inf}}^{\text{periodic}}(F_{\text{inf}}) - C(F_{\text{inf}})}{\partial F_{\text{inf}}} \\
 & = \left(\frac{C_{\text{inf}}^2 T M_{\text{inf}} \text{Prob}_{1.2}}{D_{\text{inf}}^- D_{\text{sup}}^+} \right) \cdot F_{\text{inf}}^*{}^2 \\
 & + \left(-\frac{M_{\text{sup}} C_{\text{inf}} T^2}{D_{\text{sup}}^+} \text{Prob}_1 - \frac{2G_{\text{inf}} r_{\text{inf}}}{\delta} - \frac{C_{\text{inf}} M_{\text{inf}}}{D_{\text{inf}}^-} \text{Prob}_{1.2} + \frac{M_{\text{inf}} C_{\text{inf}} T}{D_{\text{sup}}^+} \text{Prob}_{1.1} \right) F_{\text{inf}}^* \\
 & + (\text{Prob}_1 M_{\text{sup}} T - \text{Prob}_{1.1} M_{\text{inf}}) = 0
 \end{aligned} \tag{8}$$

Equation (8) can be resolved with respect to the flexibility potential of the inferior process by applying the solution formula for quadratic equations:

$$\begin{aligned}
 F_{\text{inf}}^* & = \\
 & = \frac{\frac{M_{\text{sup}} C_{\text{inf}} T^2}{D_{\text{sup}}^+} \text{Prob}_1 + \frac{2G_{\text{inf}} r_{\text{inf}}}{\delta} + \frac{C_{\text{inf}} M_{\text{inf}}}{D_{\text{inf}}^-} \text{Prob}_{1.2} - \frac{M_{\text{inf}} C_{\text{inf}} T}{D_{\text{sup}}^+} \text{Prob}_{1.1}}{\frac{2C_{\text{inf}}^2 T M_{\text{inf}} \text{Prob}_{1.2}}{D_{\text{inf}}^- D_{\text{sup}}^+}} \\
 & - \sqrt{\left(-\frac{M_{\text{sup}} C_{\text{inf}} T^2}{D_{\text{sup}}^+} \text{Prob}_1 - \frac{2G_{\text{inf}} r_{\text{inf}}}{\delta} - \frac{C_{\text{inf}} M_{\text{inf}}}{D_{\text{inf}}^-} \text{Prob}_{1.2} + \frac{M_{\text{inf}} C_{\text{inf}} T}{D_{\text{sup}}^+} \text{Prob}_{1.1} \right)^2 + \text{Prob}_{1.2} \frac{4C_{\text{inf}}^2 T M_{\text{inf}}}{D_{\text{inf}}^- D_{\text{sup}}^+} \cdot (\text{Prob}_1 M_{\text{sup}} T - \text{Prob}_{1.1} M_{\text{inf}})}{\frac{2C_{\text{inf}}^2 T M_{\text{inf}} \text{Prob}_{1.2}}{D_{\text{inf}}^- D_{\text{sup}}^+}}
 \end{aligned} \tag{9}$$

Now the same approach is used for values of the flexibility potential exceeding the case distinction threshold:

$$\begin{aligned}
 \text{For } F_{\text{inf}} > \frac{D_{\text{inf}}^-}{C_{\text{inf}}} : & \frac{\partial \delta I_{\text{inf}}^{\text{periodic}}(F_{\text{inf}}) - C(F_{\text{inf}})}{\partial F_{\text{inf}}} \\
 & = -\left(\frac{C_{\text{inf}} T}{D_{\text{sup}}^+} \cdot \text{Prob}_1 (M_{\text{sup}} T - M_{\text{inf}}) + \frac{2G_{\text{inf}} r_{\text{inf}}}{\delta} \right) F_{\text{inf}}^* \\
 & + (\text{Prob}_1 M_{\text{sup}} T - \text{Prob}_{1.1} M_{\text{inf}}) = 0
 \end{aligned} \tag{10}$$

Again resolving equation (10) with respect to the optimal flexibility potential of the inferior process determines the optimum:

$$F_{\text{inf}}^* = \frac{\text{Prob}_1(M_{\text{sup}}T - M_{\text{inf}})}{\frac{C_{\text{inf}}T}{D_{\text{sup}}^+} \cdot \text{Prob}_1(M_{\text{sup}}T - M_{\text{inf}}) + \frac{2G_{\text{inf}}r_{\text{inf}}}{\delta}} \quad (11)$$

Optimal flexibility potential of the superior process

For the derivation of the optimal level of flexibility potential of the superior process, the same approach is applied as for the optimal flexibility of the inferior process:

$$\frac{\partial \delta I_{\text{sup}}^{\text{periodic}}(F_{\text{sup}}) - C(F_{\text{sup}})}{\partial F_{\text{sup}}} = \left(\frac{C_{\text{sup}}^2}{TD_{\text{sup}}^- D_{\text{inf}}^+} \right) \cdot F_{\text{sup}}^{*2} - \left(\frac{C_{\text{sup}}}{TD_{\text{inf}}^+} + \frac{C_{\text{sup}}}{D_{\text{sup}}^-} + \frac{2TG_{\text{sup}}r_{\text{sup}}}{\text{Prob}_{2.1}\delta M_{\text{inf}}} \right) F_{\text{sup}}^* + 1 \quad (12)$$

$$= 0$$

Using again the solution formula for quadratic equations the optimal flexibility of the superior process can be determined:

$$F_{\text{sup}}^* = \frac{\frac{C_{\text{sup}}}{TD_{\text{inf}}^+} + \frac{C_{\text{sup}}}{D_{\text{sup}}^-} + \frac{2TG_{\text{sup}}r_{\text{sup}}}{\text{Prob}_{2.1}\delta M_{\text{inf}}} - \sqrt{\left(-\frac{C_{\text{sup}}}{TD_{\text{inf}}^+} - \frac{C_{\text{sup}}}{D_{\text{sup}}^-} - \frac{2TG_{\text{sup}}r_{\text{sup}}}{\text{Prob}_{2.1}\delta M_{\text{inf}}} \right)^2 + 4 \frac{C_{\text{sup}}^2}{TD_{\text{sup}}^- D_{\text{inf}}^+}}}{2 \frac{C_{\text{sup}}^2}{TD_{\text{sup}}^- D_{\text{inf}}^+}} \quad (13)$$

VI Results, Limitations and Future Research

Chapter VI presents the results of the doctoral thesis (Section VI.1) and points out areas of future research as well as limitations (Section VI.2).

VI.1 Results

The main objective of this doctoral thesis is to provide support for making good IS decisions with a special focus on the problem field of business processes. Therefore, it follows a two-sided strategy: Applying descriptive decision theories on IS decision problems to identify situations where practical decision-makers potentially make wrong decisions (research objectives II) and developing rational decision procedure to assist practical decision-makers (research objectives III, IV and V). In combination both streams of decision theory help practical decision-makers to manage the enormous complexity of IS decisions which arises from three key characteristics of IS: dynamism, innovativeness, and interdependencies. Dynamism refers to the high pace of the technological progress which continuously enhances and changes decision alternatives. Successful business models can immediately become obsolete with a new, disruptive invention. Closely related is the innovativeness of IS. Organization can typically not draw from an extensive knowledge base on new technologies. Their actual impacts within the organizational environment can often only be guessed and practical decision-makers need to rely on their intuitions when deciding about which trends will really be valuable and which are only short-term fashions. Moreover, IS decisions always influence the whole organizational architecture and the inherent interdependencies. IS decisions mean evaluating business models, redesigning business processes and setting up suitable technological backbones. This doctoral thesis aims at helping practical decision-makers to succeed in this complex system and at increasing the business value of IS in general.

As for the descriptive contributions, chapter II applies prospect theory as probably the most acknowledged theory on human decision behavior to show that typical behavioral patterns may indeed lead to wrong IS decisions. Although chapter II is devoted to IS decisions in the broad interpretation, the fundamental results can be specified for the single layers of the organizational architecture. For IS in general, chapter II reports that loss aversion and asymmetric risk attitudes make decision-makers to irrationally prefer less valuable cost investments, i.e. investments that decrease operational costs over more valuable revenue investments, i.e. investments that strengthen the competitive position of the organization. A

similar one-sided perception can be observed in business process redesign, where decision-makers mainly count on exploitative designs which improve operational process performance. In comparison, explorative designs which aim to increase the customer value are often neglected. The behavioral patterns of prospect theory can again explain such a one-sided perception. Once decision-makers become aware of their subconscious misperceptions, they can force themselves to question their intuitions and avoid wrong decisions.

As for the normative contributions of this doctoral thesis in chapters III-V, the research papers report on rational decision procedures for big data analytics (research objective III) and for the three activities process redesign (research objectives IV and V). Methodologically, all decision models combine normative analytical modeling and value-based management as central paradigms. Normative analytical modeling means transcribing the essentials of a decision problem into mathematical representations to produce prescriptive results (Meredith et al. 1989). This paradigm can help to manage key challenges of IS decisions by structuring the complexity of the decision problems, incorporating multiple types of effects, and resolving conflicts (trade-offs) among the conflicting effects. Especially for overcoming the last two aspects of multiple types of conflicting effects, this doctoral thesis additionally applies value-based management (VBM) as valuation frame. VBM aims to sustainably increase an organization's firm value (Koller et al. 2010). On a high level, this means that all corporate decisions must be aligned to the objective of maximizing the firm value. On the operative level, the orientation at the firm value requires decisions to be made on the basis of cash flow effects (Buhl et al. 2011). Thereby, the multiple types of effects can be reduced to the common basis of cash flows making them comparable and structurable. Although the normative models presented in this doctoral thesis can be criticized for operating on structuring assumptions and on an artificial image of reality, the normative procedures are definitely valuable and necessary for decision-makers. The central point is that decision-makers also need to simplify IS decisions when not relying on supportive tools. This is because the cognitive capacity is typically not sufficient for the complexity of many IS decision problems. The mathematical models of this thesis can process a higher complexity and therefore a more realistic representation of reality. It is important to note that the provided prescriptions cannot be understood as business value estimates, i.e. they do not forecast realized cash flows, but they give recommendations on decision alternatives. As all models provide robustness analyses on their recommendations, they can be easily plausibilized by decision-makers. Therefore, normative decision models

as presented in this thesis are deeply needed in practice and normative decision theory is a highly valuable research field in the context of IS.

In the following, the results of the included research papers are presented. This thesis closes with discussing limitations of the results and areas of future research in Section VI.2.

VI.1.1 Results of Chapter II: Descriptive IS Decision Theory – Investigating Paradoxes Inherent to the Business Value of IT

In Section II, research paper 1 develops the concept of the perceived business value of IT (BVIT) to explain irrational IT decision-making. Thereby, the perceived BVIT is defined as the decision-maker's mental interpretation of potential IT performance effects. True and perceived business values are thus different constructions of the same object and are closely related. As the origin of all IT decisions, the perceived BVIT determines which IT investment opportunities are chosen by the practical decision-maker. Thus it also defines the existent IT by filtering opportunities so that only IT investments with high perceived BVIT are executed and create BVIT. The key problem inherent to the perceived BVIT is that it is deferred by perception patterns (Kahnemann and Tversky 1979), which can evoke wrong decisions. Therefore, in reality, the realized BVIT is often lower than it could be.

To quantify the effects of these biases, research paper 1 develops a quantitative approximation for the perceived BVIT by applying prospect theory (PT). This representation shows that the classical biases, inherent in human value perception, can indeed explain (next to other potential explanations) the preference of cost investments over revenue investments (perception paradox) and the structural overvaluation of IT benefits (new productivity paradox). The better understanding of the roles of the PT-mechanics helps to derive solutions and retaliatory actions. One possibility is an adjustment of the corporate culture. Once a decision-makers perceives IT as a value driver, and not as a cost factor, the value perception turns automatically correct. Although the basic mechanisms of PT still hold, framing effects are eliminated by such a rethinking and preferences of less valuable cost investments are no longer given. A second alternative is the establishment of an adequate corporate governance. As governance mechanisms are shown to prevent loss aversion and asymmetric risk attitudes in organizational decision-making and, they resolve ambiguous perceptions at its origin. Overall, the scientific contribution of research paper 1 is twofold. First, it develops the new construct of the perceived BVIT on the basis of one of the most honored economic theories. Thereby, it expands the toolkit for future analyses in BVIT research. Second, the application of the quantitative approximation for the BVIT analytically

shows that irrationalities in human decision behavior can explain the existence of the two fundamental paradoxes and indicates possible solutions.

VI.1.2 Results of Chapter III: Normative Guidance on IS Decisions – How to Evaluate Investments in Big Data Analytics

Chapter III takes the normative perspective on IS decision-making and especially demonstrates the usefulness of normative theories to manage the innovative and dynamic character of IS decision for the example of the example of big data analytics (BDA) (research objective III). Research paper 2 develops a modular framework that helps organizations to make sound decisions on BDA. Thereby, it first analyzes the economic mechanisms of value creation of BDA, makes this value creation tangible by explicitly considering data-induced actions and provides two mathematical representations deliberately designed for central practical use cases.

The prescriptive contribution of research paper 2 lies in extending the value of imperfect information introduced by Stratonovich (1965) for the particularities of BDA: velocity and variety. As for velocity, the deteriorating effect of latency times on the value of information is implemented by Hackathorn's (2004) time-value-curve. Markowitz's portfolio theory (1952) provides the theoretical foundations for constructing information portfolios which are used to implement value effects of variety. Thus, research paper 2 provides a theory-based understanding of the value creation of BDA, and concrete guidance on how to assess its business value.

After having validated the model's design specification with the head of the big data department of a large German insurance company, research paper 2 provides two representations deliberately tailored to central problems: in-depth value analysis of single information and strategic prioritization of the four Vs (velocity, veracity, variety and volume). As for single information, the big data department struggles with the issue that their analytics engine generates too many significant patterns that they cannot identify valuable patterns to be integrated in their policy making process. The decision model of research paper 2 enables the separate evaluation of data patterns and addresses this first practical need. Addressing the strategic prioritization of the four Vs means that the model enables analyses of the stand-alone relevance of the four Vs. This capability helps to incrementally evolve the current IS to a mature BDA system. Research paper 2 demonstrates the usefulness of the model in the real-world case of the large German insurance company in the context of insurance telematics.

VI.1.3 Results of Chapter IV: Normative Guidance on Strategic Redesign Decisions

Chapter IV outlines normative models for two strategic activities of process redesign: setting strategic objective (research objective IV.1) and generating redesign ideas (research objective IV.2). Section IV.1 combines theories from customer relationship management (CRM) and BPM to identify processes where the standard objective of improving operational performance should be replaced by stronger customer-centricity. Section IV.2 develops an application of computational intelligence which uses the functionalities of evolutionary algorithms (EA) to improve existing process designs in simulative cycles into new process designs by subsequently changing small design elements, keeping valueable changes and abandoning poor changes per cycle.

In Section IV.1, research paper 3 develops an analytical framework that helps organizations to decide whether a process should follow exploitative (efficient) or explorative (customer-centric) design objectives. Thereby, it supports Rosemann (2014) who criticizes a one-sided focus on operational performance in BPM academia and practice. Fulfilling both strategic targets in parallel is typically not possible as efficiency requires automated and standardized routines that are deliberately designed to deliver a defined output, whereas customer-centricity demands the provision of a broad output range to meet diverse customer needs. Research paper 3 defines this tension field as the experience-efficiency-trade-off (E-E-trade-off). For solving this central trade-off, research paper 3 combines descriptive results from CRM in form of the Kano model (Kano et al. 1984) with prescriptive best practices from BPM. Kano et al. (1984) state that products or service (in general process outputs) can be divided into three classes with different customer mechanics: excitement, performance and basic outputs. If excitement outputs exceed customer expectations, customer profitability increases exponentially, while underfulfillments are not punished with decreasing profitability. The opposite holds for basic outputs. Performance outputs linearly decrease/increase with under/overfulfillment. Research paper 3 transfers this logic to business processes and categorizes them accordingly into the three classes. For excitement processes with the exponential increase in case of overfulfillment and the absence of any downside risk in case of underfulfillment, organizations should use risk-taking designs and concentrate on customers if they have the opportunity to reach the area of overfulfillment. For basic processes, organizations should respect the one-sided risk of decreasing profitability in case of underfulfillment and concentrate on efficient designs that ensure that customer expectations are not underfulfilled. Concerning performance processes, research paper 3 distinguishes between demanding and easy customers while recommending efficient designs

for easy customers and customer-centric designs for demanding customers. Research paper 3 builds an analytical model which compiles the results from the Kano model (Kano et al. 1984) into cash flow effects to integrate them with existing models from value-based BPM (Bolsinger et al. 2011). Based on this model, the analytical analyses of the paper support the qualitative results on strategic redesign objectives. Overall, this paper is the first to address and solve the E-E-trade-off and thus contributes to literature in helping to leave the one-sided concentration on operational process performance.

In Section IV.2, research paper 4 addresses the second strategic activity of process redesign: generating redesign ideas. Therefore, it takes up the academic call for more applications of computational intelligence (Vanwersch et al. 2015) and uses evolutionary algorithms (EA) to support practical decision-makers. The continuous redesign pressure often exceeds cognitive capacities of human beings and requires computational solutions that provide an objective basis for further discussions in a redesign committee. With its conceptual analogies to the BPM lifecycle – the most popular redesign framework in practice – the algorithm transfers successful cognitive approaches from human decision-makers to the computational level. The computational lifecycle is not prone to human biases and less limited in processing complexity. On the process level, the algorithm operates on all key process elements (i.e., activities, resources, and their logical connections), produces feasible designs that deliver the predefined output and evaluates new designs on an accepted valuation function from value-based management. As core contributions, the algorithm is the first application of EA that can process decision points and guide process flows on realizations of decisive attributes. This enhancement makes the algorithm more applicable in real-world scenarios. Research paper 4 analyzes the applicability, usefulness, and performance of the algorithm, in artificial test settings. These analyses show that the algorithm can produce promising design ideas in an acceptable processing time and that it can rank designs in an unambiguous order.

VI.1.4 Results of Chapter V: Normative Guidance on Operational Redesign Decisions

Chapter V addresses operational decisions on business process standardization (BPS) (research objective V.1) and business process flexibility (research objective V.2). As for BPS, research paper 5 utilizes descriptive knowledge on the effects of BPS on process performance and builds an analytical decision model that integrates these effects. Research paper 6 covers the topic of business process flexibility.

In chapter V.1, research paper 5 investigates how organizations should decide about an appropriate BPS level, considering the partially conflicting effects that BPS has on process performance. The interplay between these conflicting effects builds the BPS trade-off. As first contribution, the decision model structures BPS effects and modularly compiles them to value contributions for generating a common scale measurement. As second contribution, the decision model formalizes different BPS levels via the concept of process variant profiles. Technically, process variant profiles are vectors that assign the master process or a context-specific process variant to process contexts. As third contribution, the decision model is the first approach that derives optimal BPS levels from a holistic perspective. The optimal BPS level is reached when demand reductions induced by decreasing process flexibility can be overcompensated by higher demand trends that flow from better quality and time. From a cost perspective, the optimal BPS level overcompensates investment outflows with higher profit margins that flow from experience effects. For validating the practical usefulness of the decision model, research paper 5 uses a two-sided strategy: First and from a theoretical perspective, the design specifications are evaluated against knowledge from justificatory literature. Second and from a practical perspective, a prototypical implementation of the model is tested in the real-world case of an insurance broker pool company. In Chapter V.II, research paper 6 presents a decision model about the optimal level of process flexibility. Thereby the abstract concept of process flexibility is operationalized as the fraction of process capacity that can be reallocated from one process (variant or design) to another. With its economic set up, the model addresses the shortcomings of existing approaches by explicitly considering the positive economic effects of process flexibility. The model covers the classical effect of balancing risky demand distributions and accounts for further process characteristics such as criticality, similarity, and variability. Again the model utilizes value-based management as theoretical foundation by considering cash flow, multi-period planning horizon, and risk-adjusted interest rate. Similar to research paper 5, the model's applicability and usefulness is investigated in the context of the broker pool company.

VI.1.5 Conclusion

Summarizing the results of the research papers, this doctoral thesis contributes to improving IS decision-making. As for descriptive IS decision theory, research paper 2 identifies human value perception as potential origin for wrong IS decisions and provides ideas for debiasing practical decision-makers. Research papers 2 to 6 provide normative decision tools that help practitioners to manage the complexity of IS decisions.

VI.2 Limitations and Future Research

This section outlines potential aspects for future research for the topics of the respective chapters and discusses limitations of the respective results.

VI.2.1 Descriptive IS Decision Theory – Investigating Paradoxes Inherent to the Business Value of IT

Research paper 1 investigates the role of human perception patterns on IT investments. Hence the key results are mainly theoretical or conceptual and require empirical validation. The application of prospect theory (PT) confirms extant research results from another perspective. Thus, its theoretical contribution is not a radical reinvention but rather a complementation. Only quantitative and empirical analyses can finally validate whether the new perspective of PT really increases the explanatory power of BVIT theory. From a conceptual side, the concept of the perceived BVIT supposes two central hypotheses for such empirical validations. First, the more pronounced a firm's loss aversion and asymmetry of risk attitudes are, the larger will be the share of total investments dedicated to the reduction of operational costs. Second, the pronunciation of PT-patterns will lead to higher perceived failure rates of the firm's IT investments. The appropriate methodology for validating these hypotheses is probably an empirical field study. Loss aversion and asymmetry of risk attitudes can represent the independent variables. The ratio between cost and revenue investments for the first hypothesis, and the perceived failure rate for the second hypothesis, can serve as dependent variables. If empirical analyses illustrate significantly positive and substantial relationships, the validity of the perceived BVIT can finally get accepted.

VI.2.2 Normative Guidance on Strategic Redesign Decisions

Research paper 2 develops a rational decision procedure on big data analytics (BDA) and demonstrates the usefulness of normative decision theory for decisions about innovative technologies. A central problem that is inherent to this innovative character is anticipation. Using a normative decision model does not replace an understanding about how a technology would affect an organization. Decision-makers are still required to have at least a vision about this impact. Decision models can help to structure problems and to condense them to their essentials, as demonstrated by research paper 2 when concentrating the technological decision about measuring technologies in insurance telematics to market penetration and user behavior. However, decision models cannot operate on effects that cannot be anticipated.

Organizations often perceive BDA as a method to discover hidden knowledge and generate unanticipated cash flows. Although, such uncertain and unanticipated effects may indeed have business potential, research paper 2 restricts the evaluation of BDA on effects that may be intangible but which are at least definable. For further improving the decision quality of the model, future research needs to investigate and observe the complete range of organizational effects that BDA really exhibits in practice. Descriptive knowledge from case studies should be used to refine the model for effects which are currently impossible to anticipate.

VI.2.3 Normative Guidance on IS Decisions – How to Evaluate Investments in Big Data Analytics

Research paper 3 combines CRM and BPM to derive prescriptions on strategic redesign objectives. Similar to the descriptive results of research paper 1 on the perceived BVIT, the recommendations of research paper 3 mainly result from theoretical considerations. The validity of these conceptual results can only be determined by empirical investigations. Moreover, the current version of the model only provides high-level recommendations for redesign objectives on the basis of four archetype strategies. Although the model is technically able to derive target values for efficiency and process fulfillment, research paper 3 abstracts from such detailed statements. This is because these fine-grained prescriptions require the operationalization of customer sensitives. As deep, descriptive studies on this aspect of customer behavior are currently missing, a clear operationalization is not yet possible. Any results would suffer from spurious accuracies. Thus future research should investigate this theoretical construct for enabling our model to describe strategic redesign targets in detail. As third approach for further research, the model could be extended to management and support processes. In the current form, the model is restricted to business processes which have direct interfaces to end-customers. Additional work is needed to implement the indirect effects of the other process classes to expand the model's applicability and usefulness.

Research paper 4 applies develops an evolutionary algorithm (EA) to generate redesign ideas. In the current state, such data-driven BPM approaches primarily focus on process discovery or conformance checking, i.e. administrative parts of the process lifecycle (van der Aalst 2011). As, it is to be expected that the exponential growth of process data (e.g. from workflow management) will increase the advantages of computational abilities over human cognitive capacity, it is crucial to extend these experiences and results to the creative

parts of the lifecycle and especially to process redesign (van der Aalst et al. 2016). The EA as presented in research paper 4 only provides a first idea and impression about how data-driven approaches could work and about what benefits they may generate. Future research needs to combine existing knowledge on practicable, data-driven methodologies with computational intelligence to develop a closed system for a data-driven BPM lifecycle.

VI.2.4 Normative Guidance on Operational Redesign Decisions

The decision model of research paper 5 addresses the BPS trade-off and determines the appropriate level of BPS. As most decision models, also research paper 5 operates on simplifying assumptions to manage real-world complexity. The strongest assumption is the linear relationship between BPS and process quality as well as time. Although this assumption is supported by empirical findings, reality is probably more complex. Future research should extend the model accordingly. Furthermore, the decision model is deliberately constructed for business processes, i.e. processes with direct interfaces to end-customers. This focus manifests in the underlying understanding of customer behavior with process demand being related to process time and quality. Customers of support processes cannot freely choose process variants according to their preferences and are forced to demand the process output. Low process quality e.g. would not result in a reduced demand but require additional process executions which then produce additional process costs. Future research should extend the decision model to the other process classes and relax this limitation. Moreover, future research on more real-world case studies in different organizational contexts and industries is needed to build a substantial knowledge base. Although research paper 5 demonstrates the applicability and usefulness of the decision model in the context of an insurance broker pool company, the first experiences are not sufficient to provide reference data for calibrating the decision model to other application domains.

The limitations of research paper 6 provide opportunities for future research regarding the relaxation of assumptions and the consideration of cash outflows associated with establishing process flexibility. For capturing the complexity inherent to the concept of process flexibility and to structure the decision problem, research paper 6 simplifies reality to a manageable extent. In the simplified setting, the decision model identifies relevant parameters, derives their economic effects and analytically determines the optimal level of process flexibility. Most notably are the assumptions of restricting shifting capabilities for only two processes and the independent and uniformly distributed demand. Although the

reported real-world application suggests a high practical usefulness, future research should extend model to be applicable for more than two processes and for different demand distributions.

As second area for future research, the model's consideration of flexibility-related cash outflows needs to be refined. With emphasizing the positive economic effects of process flexibility, the cash outflow component is addressed in a coarse-grained manner. Future research should develop more profound mechanisms that can incorporate more process characteristics relevant to process flexibility.

VI.2.5 Conclusion

Summarizing, the research papers presented in this doctoral thesis contribute to the research context of IS decision-making and provide descriptive as well as normative knowledge that can improve the quality of IS decisions. All provided tools follow the long-term goal of increasing the business value of IS on the basis of better decisions. Typically research on the business value of IS focuses on performance effects of existing IS and does not consider that the existing IS as outcomes of prior decisions. This doctoral thesis takes the ex-ante view and analyzes how the decision problems should be approached in practice to improve the business value of IS already in the decision phase.

Although this doctoral thesis can certainly answer some selected questions, there are still many obstacles to overcome until IS decision theory reaches a mature state and comprehensively supports practical decision-makers. Considering the high pace of technological progress and the radical influences of digitalization, this doctoral thesis can hopefully provide valuable insights to practical decision-makers for managing uncertainties, for making reasonable decisions and for increasing the business value of IS.

VI.2.6 References

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