PROCESS MEETS PROJECT PRIORITIZATION – A DECISION MODEL FOR DEVELOPING PROCESS IMPROVEMENT ROADMAPS

Research paper

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Abstract

Improving business processes is a key success factor for organizations and, at the same time, a major challenge for decision makers. For process improvement to be successful, effective prioritization is essential. Despite the existence of approaches for the prioritization of process improvement projects or business processes, prescriptive research at the intersection of both research streams is missing. Existing approaches do not simultaneously prioritize business processes and improvement projects. Hence, scarce corporate funds may be misallocated. To address this research gap, we propose the PMP2, an economic decision model that assists organizations in the identification of business process improvement (BPI) roadmaps. Based on stochastic processes and simulation, the decision model maps different improvement projects to individual business processes within a process network. Thereby, it caters for process dependencies and basic interactions among projects. Drawing from the principles of value-based management, the decision model determines the process improvement roadmap with the highest contribution to the long-term firm value. To evaluate the PMP2, we instantiated it as a software prototype and performed different scenario analyses based on synthetic data. The results highlight the importance of prioritizing business processes and improvement projects in an integrated manner.

Keywords: Business Process Management, Business Process Improvement, Process Prioritization, Process Dependencies, Network Analysis.

1 Introduction

Business process improvement (BPI) is necessary to align business processes with technological, organizational, political, and other changes. By doing so, BPI ensures that companies keep pace with their business environment (Dumas et al., 2018; Coskun et al., 2008; Davenport and Perez-Guardado, 1999). Therefore, BPI has been identified as a top priority for decision makers (Harmon, 2018). However, more than 60% of process improvement projects are reported to fail (Chakravorty, 2010). This is due to organizations' focus on inappropriate processes or the improvement of too many processes simultaneously (Ohlsson et al., 2014). Hence, research that offers guidance on how to successfully implement process improvement projects is in high need (Zellner, 2011). One critical success factor is thereby effective prioritization.

In the BPI domain, prioritization approaches either use business processes or process improvement projects as unit of analysis. As for process prioritization, the literature encompasses many approaches mostly centered around individual processes (Lehnert et al., 2018). In practice, however, business processes are interconnected (Dijkman et al., 2016). Thus, it has become consensus in recent research that process dependencies need to be considered when prioritizing processes to avoid a misallocation of corporate funds and to increase the long-term firm value (Kratsch et al., 2017; Dijkman et al., 2016). The literature on dependency-aware process prioritization is continuously growing. Huxley (2003), for example, discusses process selection with a focus on critical processes. Based on Google's PageRank, the ProcessPageRank is another approach that accounts for dependencies among processes when determining their need for improvement (Lehnert et al., 2018). Kratsch et al. (2017) develop another method considering dependencies while obtaining information from process models and logs. While all these approaches assist in the identification of processes in need for improvement, they lack the "improvement project" perspective. Hence, they fail to bridge the gap between process prioritization and the prioritization of respective improvement projects. As for the prioritization of process improvement projects, Linhart et al. (2015) use established industrialization strategies to analyze which projects to implement in which sequence to improve an individual process. As another example, Ohlsson et al. (2014) propose a process assessment heat map and a process categorization map to prioritize improvement initiatives. Lehnert et al. (2016) develop a planning model that determines BPM roadmaps including projects that either improve individual processes or develop an organization's BPM capability. All these approaches, however, neglect process dependencies. In a nutshell, while extensive research has been conducted on both the prioritization of business processes and the prioritization of process improvement projects, the intersection of both streams yet needs to be explored. Hence, our research question is as follows: *How can process improvement projects be scheduled while considering process dependencies to maximize an organization's long-term firm value?*

To address this research question, we develop the PMP2, an economic decision model. By combining Markov reward models (MRM) and normative analytical modeling, PMP2 assists organizations in determining *BPI roadmaps,* which maximize an organization's long-term firm value while catering for process dependencies and interactions among projects. We define BPI roadmaps as the sequential implementation of improvement projects on business processes. Thereby, PMP2 takes a multi-period, multi-process, and multi-project perspective. An application example of the PMP2 could be the integration of IoT applications into a smart factory. Within a smart factory there are several production processes using procurement processes and triggering sales processes. The PMP2 considers decencies between processes and improvement projects and thus schedules improvement projects to processes optimizing an organizations long-term firm value.

With decision models being valid design artefacts (March and Smith, 1995), we adopt the design science research (DSR) paradigm as per (Gregor and Hevner, 2013). Following the DSR reference process (Peffers et al., 2007), this section covers the identification of the research gap. In Section 2, we derive design objectives of a solution based on justificatory knowledge. In Section 3, we present the design specification of our PMP2. In Section 4, we report our evaluation results, while we conclude in Section 5 by pointing to limitations and future research.

2 Theoretical Background and Design Objectives

2.1 Business Process Improvement

BPM is "the art and science of overseeing how work is performed to ensure consistent outcomes and take advantage of improvement opportunities" (Dumas et al., 2018, p.1). The tasks performed in BPM, i.e. the identification, definition, modelling, implementation, execution, monitoring, controlling, and improvement of processes, are structured along lifecycle models (Recker and Mendling, 2016). Organizations conduct BPI projects to adapt their business processes to changing business environments (Dumas et al., 2018; Coskun et al., 2008). Therefore, BPI has been identified as a top priority for decision makers (Harmon, 2018). Recent research agrees that improvement projects can affect the performance of processes in several ways. Therefore, the effects of process improvement projects are typically captured in terms of performance indicators. For example, the Devil's Quadrangle is a performance framework that includes time, cost, quality, and flexibility as performance dimensions (Reijers and Linmansar, 2005). This leads to the first design objective:

(DO.1) To appropriately schedule BPI projects in process networks, multi-dimensional effects of improvement projects on process performance must be considered.

2.2 Process Dependencies

Business processes are structured sets of activities designed to create specific outputs (Davenport, 1993). In practice, hardly any process is executed in isolation. Instead, they are organized in process networks, i.e. multiple interdependent processes (Lehnert et al., 2016). Hence, an understanding of process dependencies is key for decision makers (Dijkman et al., 2016). Process repositories and business process architectures (BPA) are the most common contexts in which process dependencies are currently used (Dijkman et al., 2016; Malinova et al., 2015). The four most frequent inter-process dependencies are specialization, decomposition, use, and trigger (Dijkman et al., 2016). Trigger relations express that one process' execution triggers the execution of another process without depending on its output. Use relations indicate that one process creates output that is required by the using process to continue its execution or terminate. While catering for process dependencies is established in descriptive research, fewer approaches consider process dependencies for prescriptive purposes such as process prioritization (Kratsch et al., 2017). As many process dependencies exist in practice, recent research agrees that they are an essential input when prioritizing processes (Kratsch et al., 2017; Dijkman et al., 2016). Therefore, we define our second design objective:

(DO.2) To appropriately schedule BPI projects in process networks, process dependencies must be considered.

2.3 Value-based Decisions in BPM

In recent research, value-based management (VBM) became a guiding paradigm in BPM (Lehnert et al., 2016; Bolsinger, 2015). The general principles of VBM require that planning and control variables consider the time value of money and the risk attitude of the decision makers. Moreover, these variables must be based on cash flows (Buhl et al., 2011). The value-based BPM approach adopts the general principles of VBM to maximize an organization's long-term firm value by making process decisions according to their value contribution (Buhl et al., 2011). From a valuation perspective, processes and BPM are considered as corporate assets (Bolsinger et al., 2015). Numerous paradigms relate to value-based BPM, such as value-focused BPM (Neiger and Churilov, 2004) or value-oriented BPM (vom Brocke et al., 2010). As we aim to evaluate BPI roadmaps in an economically well-founded manner, we adopt value-based BPM as guiding paradigm. Therefore, we state our third design objective:

(DO.3) To appropriately schedule BPI projects in process networks, cash-flow effects, the time value of money, and the risk attitude of the involved decision makers must be considered.

3 Design Specification of the PMP2

3.1 General Framework and Assumptions

In line with the principles of VBM, the PMP2 aims to identify the BPI roadmap that maximizes an organization's long-term firm value (Ittner and Larcker, 2001; Martin and Petty, 2000). To do so, the model requires process characteristics (e.g. process dependencies, process lead time) and project characteristics (e.g. modification target, modification factor) as input parameters. In a first step, the model takes these input parameters and compares different process improvement projects by analyzing the process network after a distinct improvement project has been implemented. In a second step, it schedules different improvement projects from a value-based investment perspective, resulting in a BPI roadmap. Hence, the PMP2 follows a two-step approach, comprising a process network analysis and an investment analysis (Figure 1).

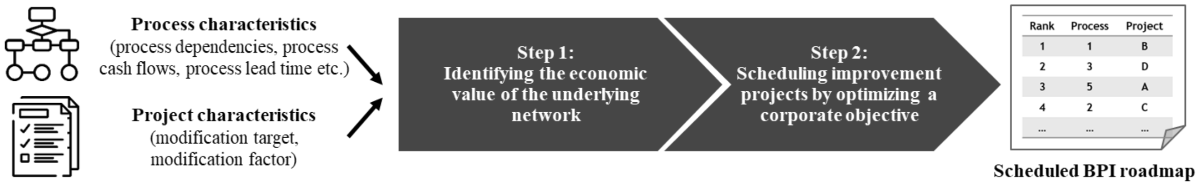

Figure 1: The PMP2's two-step approach

For model development, we build on the method of Markov reward models (MRM) and normative analytical modeling. Normative analytical modeling captures the essentials of a decision problem by mathematical representations to produce a prescriptive result (Meredith et al., 1989). Such analysis provides support in structuring decision problems, optimizing trade-offs among different criteria against a given target function and enable a well-founded choice between decision alternatives (Keeney and Raiffa, 1993).

As for MRM, we use an absorbing, first-order continuous time Markov Chain (CTMC) as an underlying stochastic process. The application of such MRMs to the prioritization of improvement projects in process networks is sensible for many reasons. CTMC's mathematical foundation in stochastic processes as well as in probability theory enables accounting for dependencies among states and estimating expected future values (Styan and Smith, 1964). Therefore, process dependencies in form of use and trigger dependencies that can be captured for example via process mining can be addressed. Additionally, the future economic value of BPI roadmaps can be estimated. Embedding CTMCs into an MRM further enables the predictive characteristic of the PMP2 needed for the selection of the optimal BPI roadmap. Other approaches such as stochastic Petri Nets (SPN) may offer the same or an even better fit when focusing on modeling business processes. However, Molloy (1981) has shown that SPNs are isomorphic to CTMC. Hence, SPNs can be transferred into CTMCs or MRMs and vice versa (Ciardo et al., 1994). Since we do not focus on the explicit modeling of a process network but on the value-based investment perspective within these networks, we do not require the additional details provided by Petri Net representation. Thus, we will focus on the mathematical foundation and use the more general MRM.

Table 1 shows how we consider different BPM elements within the PMP2 (MRM) while Figure 2 represents an illustrative process network, modeled as a CTMC. Transferred to a BPM context, the states of the CTMC represent different processes within a company. The cash flows each process generates during one single time unit are described by the reward rate *CF*. These cash flows could for example represent the sum of the cash flows of a production machine within a smart factory per time unit. The dwelling time within one state represents the process lead time. During each execution of the process network, a product with the value *PV* is manufactured.

BPM	*PMP2 (MRM/CTMC)*
Process	**State**
Cost	**Reward rate**: Process cash flow per time
(Process lead) time	**Dwelling time**: Exponentially distributed with the factor $\lambda_{j,j}$
Quality	**Reward rate**: Process cash flow per time
Flexibility/ Dependencies between processes	**Transition rate**: The probability to jump from process j to k is defined by the transition rates quotient $\lambda_{j,k} / \lambda_{j,j}$

Table 1: Consideration of BPM elements within the PMP2

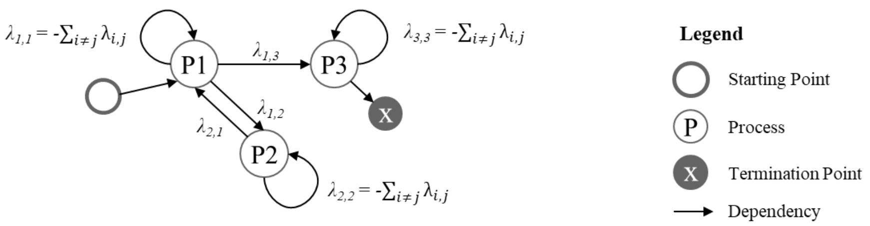

Figure 2: Illustrative process network

To apply CTMCs to the process network context, the following assumptions are necessary:

A1 The transition from one process to another happens instantaneously. Waiting times are implicitly addressed by longer process lead times.

A2 Within one model instance, processes cannot be carried out parallel but are sequential. Parallel activities that typically occur within a production line are bundled within sub-processes.

A3 The performance (process lead time, cash flow per time) of a consecutive state is independent of the previous states' performance.

These assumptions fit the widely acknowledged framework of Porter's value chain, which describes the value creation process within a (manufacturing) organization as a sequence of processes (Porter, 1985). We are aware that Porters value chain is a generic value configuration and more sophisticated approaches like the value network exist (Stabell and Fjeldstad, 1998). While the PMP2 cannot explicitly map parallel activities, we consider such activities implicitly by bundling them within sub-processes. Since we do not focus on the explicit modelling of process networks but the financial investment perspective within these networks, we build on the framework of Porter. Thus, the complexity remains manageable within an initial modeling approach. For technical reasons, we include a *Termination state*. The *Termination state* features no outgoing edges and therefore covers the absorbing Markov Chain property representing the end event of the process network. Within the state vector P, p_N represents the *Termination state*.

$$P = (p_{j=1} \quad \cdots \quad p_N)^T \tag{1}$$

The reward rate, or cash flow cf_j, generated in each process p_j during the interval $(0, \tau)$ is generally described as the integral of the reward rate over the respective dwelling time. However, as we assume the reward rate to be uniformly distributed, the cash flow generated during one single time unit can be simplified and captured by the cash flow vector CF with cf_j representing the cash flow of process p_j.

$$CF = (cf_{j=1} \quad \cdots \quad cf_N)^T \tag{2}$$

The transition rate from one process p_j to another process p_k is captured in terms of the transition rate matrix Λ shown in Eq. 3.

$$\Lambda = \begin{bmatrix} \lambda_{j,k} & \cdots & \lambda_{j,N} \\ \vdots & \ddots & \vdots \\ \lambda_{N,k} & \cdots & \lambda_{N,N} \end{bmatrix} \tag{3}$$

Mathematically, the matrix features positive off-diagonal entries and the diagonal elements $\lambda_{j,j}$ are constrained to be $-(\Sigma_{k\neq j}\, \lambda_{j,k})$. Consequently, the row sums of Λ are zero. Furthermore, the process lead time of each process is exponentially distributed with the rate $\lambda_{j,j}$. The transition probability of making a transition from process p_j to process p_k (where k≠j) in time dt is given by $\lambda_{j,k}$ dt. Within the context of homogenous continuous time Markov Chains, the transition probability at the jump point can further be described as $\lambda_{j,k} / \lambda_{j,j}$ as the transition rate matrices are constant over time. Consequently, the transition rates are the mathematical representation of the dependencies within a process network. For example, within a smart factory this enables the modelling of production processes using procurement processes and triggering sales processes.

3.2 Phase 1: Network Analysis

An existing process network can be modified by implementing different process improvement projects m_i, with $i \in \{1, ..., M\}$. An example of such an improvement project could be the integration of IoT applications into a smart factory. The aim of the network analysis is to derive the economic value of the respective network, i.e. the network value (*NV*), in period $\tau \in \{0,...,T\}$ after such an improvement project has been successfully implemented. To account for the different effects of improvement projects, it is necessary to either modify the cash-flow matrix *CF* in case of improvement projects targeting cost or quality or to modify the transition rates in case of improvement projects targeting time or flexibility. We therefore introduce two types of *modification factors* accounting for these different *modification targets*. We further assume:

A4 Within one period, an improvement project can only be implemented on one process and cannot directly affect multiple processes.

With M improvement projects and N processes within the process network, the modification matrix $CFM_\tau^{i,j}$ holding $2 * M * N$ modification factors, as each improvement project may show different effects depending on the respective process. Referring to a distinct combination, $cfm_\tau^{i,j}$ specifies a distinct *modification factor*, thus the relative modification effect of improvement project m_i on cash flows per time of process p_j in period τ (Eq. 4).

$$CFM_\tau^{i,j} = \begin{bmatrix} cfm_\tau^{i,1} & \cdots & cfm_\tau^{i,N} \end{bmatrix}^T \quad \forall \text{ i} \in \{1,\ldots,\text{M}\}, \tag{4}$$

$$\text{with } cfm_\tau^{i,j} = \begin{cases} [0,1] & \text{if reducing effect on the NV} \\ [1,\infty) & \text{if increasing effect on the NV} \end{cases}$$

Analogously, $\lambda m_\tau^{i,j,k}$ specifies the *modification factor* describing the relative effect of improvement project m_i on the transition rates of process p_j as seen in Eq. 5.

$$\lambda M_\tau^{i,j,k} = \begin{bmatrix} \lambda m_\tau^{i,j,k} & \cdots & \lambda m_\tau^{i,j,N} \\ \vdots & \ddots & \vdots \\ \lambda m_\tau^{i,N,k} & \cdots & \lambda m_\tau^{i,N,N} \end{bmatrix} \forall \text{ i} \in \{1,\ldots,\text{M}\}, \tag{5}$$

$$\text{with } \lambda m_\tau^{i,j,k} = \begin{cases} [0,1] & \text{if increasing effect on the NV} \\ [1,\infty) & \text{if reducing effect on the NV} \end{cases}$$

Thus, the modified networks can be described by the state vector *P*, the modified cash flow vector $MCF_\tau^{i,j}$ (Eq. 6) and the modified transition rate matrices $M\lambda_\tau^{i,j,k}$ (Eq. 7).

$$MCF_\tau^{i,j} = \begin{bmatrix} cfm_\tau^{i,1} * cf_0 & \cdots & cfm_\tau^{i,N} * cf_N \end{bmatrix}^T \quad \forall \text{ i} \in \{1,\ldots,\text{M}\} \tag{6}$$

$$M\lambda_\tau^{i,j,k} = \begin{bmatrix} \lambda m_\tau^{i,j,k} * \lambda_{0,0} & \cdots & \lambda m_\tau^{i,j,N} * \lambda_{0,N} \\ \vdots & \ddots & \vdots \\ \lambda m_\tau^{i,N,k} * \lambda_{N,0} & \cdots & \lambda m_\tau^{i,N,N} * \lambda_{N,N} \end{bmatrix} \quad \forall \text{ i} \in \{1,\ldots,\text{M}\} \tag{7}$$

Table 2 summarizes the respective improvement projects' effects on the process network.

Modification factor	*Modification target*	*Modification effect*
[0,1]	Cash flow	Network value increases, as cost decrease
	Transition rates	Network value decreases, as process lead time increases
[1,∞)	Cash flow	Network value decreases, as cost increase
	Transition rates	Network value increases, as process lead time decreases

Table 2: Summary of the model's input-output-relations

With this information, the PMP2 can analyze the respective network after a modification has taken place. To achieve this, it simulates a sufficiently large amount S of different simulation runs through the network according to the given transition rates until the network reaches the *Termination state*. The number of required simulation runs must be determined in line with the convergence behavior (Brooks and Gelman, 1998). Within each process along the simulation, a random process lead time $lt_{\tau,k,r}^{s,i,j}$ is drawn from the respective exponential distribution. Thereby, s stands for the current simulation run, $r \in \{1, \ldots, R\}$ represents the number of instances a process is generated during the respective simulation, and τ stands for the current period. Hence, $lt_{\tau,k,r}^{s,i,j}$ stands for the random process lead time in process p_k conditioned under the implementation of m_i on p_j. The process lead time is then multiplied with the process-specific cash flow per time unit. Thus, the value contribution $pvc_{\tau,k}^{s,i,j}$ of process p_k conditioned under the implementation of m_i on p_j can be defined as

$$\mathrm{pvc}_{\tau,k}^{s,i,j} = \sum_{k}^{N} \sum_{\mathrm{r}}^{\mathrm{R}} \mathrm{lt}_{\tau,k,r}^{s,i,j} * \mathrm{cfm}_{\mathrm{i,j}} * \mathrm{cf}_{\mathrm{j}} \qquad \forall\, \mathrm{s} \in \{0, \ldots, \mathrm{S}\}, \forall\, \mathrm{i} \in \{1, \ldots, \mathrm{M}\}, \forall\, \mathrm{j} \in \{0, \ldots, \mathrm{N}\}, \forall\, \tau \in \{0, \ldots, \mathrm{T}\}. \tag{8}$$

From that, the network value $nv_{\tau}^{s,i,j}$ under the improvement project m_i on process p_j can be derived for each simulation run s as

$$nv_{\tau}^{s,i,j} = \mathrm{PV} + \sum_{k}^{N} pvc_{\tau,k}^{s,i,j} \qquad \forall\, \mathrm{s} \in \{0, \ldots, \mathrm{S}\}, \forall\, \mathrm{i} \in \{1, \ldots, \mathrm{M}\}, \forall\, \mathrm{j} \in \{0, \ldots, \mathrm{N}\}, \forall\, \tau \in \{0, \ldots, \mathrm{T}\}. \tag{9}$$

Thus, $nv_{\tau}^{s,i,j}$ describes the value generated during one network simulation run. Depending on the network modification, one network simulation run has a duration of $\omega^{s,i,j}$, which can be measured in, for instance, hours or days. Thereby, $\omega^{s,i,j}$ is defined as the accumulated process lead time over one network simulation run. Further, the length of one planning period τ is characterized by the variable θ, quantified in the same measurement unit as $\omega^{s,i,j}$. Thus, the number of network instances that can be executed within one period τ is described by $\frac{\theta}{mean(\omega^{,i,j})}$. To calculate the value to be expected within one planning period, the mean network value is multiplied with the length of one planning period τ and divided by the mean process lead time $\omega^{i,j}$. This allows accounting for stochastic uncertainty within the process network.

$$nv_{\tau}^{i,j} = mean\left(nv_{\tau}^{i,j}\right) * \left(\frac{\theta}{mean(\omega^{,i,j})}\right) \qquad \forall\, \mathrm{i} \in \{1,\ldots,\mathrm{M}\}, \forall\, \mathrm{j} \in \{0,\ldots,\mathrm{N}\}, \forall\, \tau \in \{0,\ldots,\mathrm{T}\}. \tag{10}$$

The results of all network analyses of period τ are captured by the network value matrix NV_{τ}.

$$NV_{\tau} = \begin{bmatrix} nv_{\tau}^{1,1} & \cdots & nv_{\tau}^{M,1} \\ \vdots & \ddots & \vdots \\ nv_{\tau}^{M,1} & \cdots & nv_{\tau}^{M,N} \end{bmatrix} \tag{11}$$

3.3 Phase 2: Investment Analysis

Based on the network analyses results, the PMP2 finally determines the optimal BPI roadmap under consideration of occurring investment cash flows and underlying risk preferences. Thereby, the BPI roadmap is defined by the individual projects implemented over the planning horizon T containing periods τ, which can be measured in, for instance, months or years. For facilitation, we will consider τ to be one year.

We further assume:

A5 Within one period τ, only one improvement project can be implemented. The impact of that implementation is immediately effective.

After each period τ, the PMP2 selects which improvement project shall be implemented on which process and updates the network accordingly. Thereby, it is possible to apply the same improvement project on the same process multiple times. However, the impact of a consecutive implementation will be dampened by a degeneration effect. This is realized by applying a degeneration function $d(x)$ (e.g. the square root) to the respective modification matrix (Eq. 12, Eq. 13). This enables the convergence of the relative effect towards 1, hence an absolute effect of 0, for both increasing and decreasing effects.

$$CFM_{\tau+1}^{i,j} = d\left(CFM_{\tau}^{i,j}\right), \qquad \text{where e.g. } d(x) = \sqrt{x} \tag{12}$$

$$\lambda M_{\tau+1}^{i,j} = d\left(\lambda M_{\tau}^{i,j}\right), \qquad \text{where e.g. } d(x) = \sqrt{x} \tag{13}$$

Complying with the principles of VBM, the PMP2's objective function measures the value contribution of BPI roadmaps in terms of their NPV based on a risk-adjusted interest rate (Lehnert et al., 2016). Hence, it recommends the BPI roadmap with the highest positive value contribution. To identify a roadmap's value contribution, the value contribution of an individual improvement project in period τ must be derived first (Lehnert et al., 2016). Therefore, the network value derived during phase 1 must be reduced by the occurring investment cash flows $icf_{\tau}^{i,j}$ associated with the respective improvement project m_i on p_j.

$$vc_{\tau}^{i,j} = nv_{\tau}^{i,j} - icf_{\tau}^{i,j} \qquad \forall\, i \in \{1,\ldots,M\},\ \forall\, j \in \{0,\ldots,N\},\ \forall\, \tau \in \{0,\ldots,T\}. \tag{14}$$

Finally, the value contribution of a specific roadmap can be described as the sum of the discounted value contribution of each included improvement project. The optimal roadmap is then identified using the objective function as seen in Eq. 15.

$$RM = \underset{x \in X}{\operatorname{argmax}} \sum_{\tau}^{T} \frac{vc_{\tau}^{i,j}}{(1+z)^{\tau}}, \tag{15}$$

where: $x \in X$ is a distinct BPI roadmap from the set of admissible roadmaps X. A distinct BPI roadmap x contains a match of a distinct project to a distinct process in a distinct planning period.

$z \in \mathbb{R}_0^+$ risk-adjusted interest rate

If aiming at identifying a global optimum, exhaustive enumeration is necessary. This method is rooted in operations research and applied when no analytical solution is possible within a defined decision problem. Thereby, every possible BPI roadmap is identified, evaluated, and compared to identify the roadmap yielding the highest positive value contribution. As process networks can be highly complex, we alternatively suggest a greedy algorithm as it still yields representable results while keeping complexity manageable. The greedy algorithm we suggest is further described in the evaluation part (Section 4.3).

4 Evaluation

4.1 Evaluation Strategy

To evaluate the PMP2, we followed the established evaluation framework of Sonnenberg and vom Brocke (2012) that includes four evaluation activities: EVAL1 to EVAL4. We completed EVAL1 by justifying our research problem in the introduction and by deriving design objectives from relevant literature in Section 2. EVAL2 strives to validate the design specifications. To that end, we discussed our PMP2 against the design objectives and against competing artefacts in Section 4.2. EVAL3 intends to provide a proof of concept. Therefore, we implemented the PMP2 as a software prototype and applied it to synthetic data, conducting scenario and sensitivity analyses (Section 4.3). EVAL4 strives to validate an artefact's usefulness and applicability in naturalistic settings. This evaluation step is still outstanding and should be part of future research.

	Summary	**DO.1**	**DO.2**	**DO.3**
PMP2	*Supports the value-based matching of improvement projects and processes under consideration of process dependencies.*	*Improvement projects can affect the cost and time of processes as well as process dependencies.*	*Considers process dependencies in terms of use and trigger relations.*	*Considers cash-flow effects, the time value of money and the risk attitude of the involved decision maker.*
Lehnert et al. (2016)	Assists organization in determining which BPM- and process-level projects they should implement in which sequence to maximize firm value.	Considers the effects of projects on process performance and interactions among projects.	No consideration of process dependencies.	Carters for cash-flow effects, the time value of money and the risk attitude of the involved decision maker.
Kratsch et al. (2017)	Creates a priority list of processes for in-depth analysis based on process log data and consideration of process dependencies.	No consideration of improvement projects.	Considers both inter- and intra-process dependencies.	The prioritization of processes is partly based on cash-flow effects. The time value of money and the risk attitude of the involved decision maker are not considered.
Lehnert et al. (2018)	Ranks business processes according to their network adjusted need for improvement.	No consideration of improvement projects.	Considers inter-process dependencies.	The prioritization of processes is partly based on cash-flow effects. The time value of money and the risk attitude of the involved decision maker are not considered.
Linhart et al. (2015)	Supports improvement project selection along established industrialization strategies.	Projects influence process performance in terms of time, quality, and costs catering for trade-offs.	No consideration of process dependencies.	Considers cash-flow effects, the time value of money and the risk attitude of the involved decision maker.
Ohlsson et al. (2014)	Categorize business processes and prioritizes improvement initiatives via a process heat map and a process categorization map.	Projects influence processes according to a categorization map (in terms of differentiation, formality, and value network).	No consideration of process dependencies.	No explicit consideration of cash-flow effects, the time value of money and the risk attitude of the decision maker.

Table 3: Results of feature comparison and competing artefacts

4.2 Feature Comparison and Competing Artefacts Analysis (EVAL2)

To validate whether the PMP2 answers the research question and outperforms competing artefacts, we discuss its design specification against the design objectives and competing artefacts. As competing artefacts, we selected approaches from process prioritization and the prioritization of improvement projects. We are confident that our sample of competing artefacts covers the most recent developments even if it may not include all existing approaches. Table 3 summarizes the result of our analysis. In Table 3, the PMP2 and the competing artefacts are sorted according to their fit with our design objectives. In the following, we discuss representatives of each research stream against the PMP2. Therefore, we chose the approach of Lehnert et al. (2016) as representative for project prioritization and Kratsch et al. (2017) as representative for process prioritization, as their approaches meet our design objectives best. Lehnert et al. (2016) develop a decision model that assists organizations in determining which improvement projects to implement in which sequence to maximize their firm value. Thereby, it caters for the projects' effects on process performance and for interactions among projects. Hence, their model meets our first and third design objective. However, Lehnert et al. (2016) use individual processes as unit of analysis. Therefore, they neglect process dependencies and do not consider the second design objective. Kratsch et al. (2017) support the prioritization of processes based on process log data while considering process dependencies. Hence, they address the second design objective. Nevertheless, the improvement project perspective is missing. Thus, the first design objective is not considered. Hence, Kratsch et al. (2017) cannot provide a BPI roadmap that maps improvement projects to processes. Therefore, the third design objective is not addressed, either.

The PMP2 addresses all three design objectives. First, the PMP2 reflects that process improvement projects can influence process lead times, process costs, and dependencies of the processes within a process network. Therefore, the multi-dimensional effects of improvement projects are considered. The second design objective is addressed as the PMP2 considers inter-process dependencies in terms of trigger and use dependencies. Finally, the PMP2 selects the roadmap with the highest positive impact on the long-term firm value. Thus, the third design objective is addressed, too. As the PMP2 is the only approach to address all design objectives, it answers the research question best, outperforms existing approaches, and adds to prescriptive BPI knowledge.

4.3 Prototype Construction and Scenario Analysis (EVAL3)

To provide a proof of concept and enable real-world application, we instantiated the PMP2's design specification as a software prototype. We identified R to be a suitable environment, as it supports advanced statistical methods and offers optimization and simulation add-ons. As open source software, the use of R also corresponds with the open research idea. The prototype's logic follows the two-step approach implemented in the PMP2. To identify a global optimum, exhaustive enumeration is necessary. This results in $(N * M)^{\tau}$ possible mappings of projects to processes, i.e. $(N * M)^{\tau}!$ roadmaps, and is computationally intensive and only sensible for small numbers of processes and projects in focus. For practical feasibility, we thus applied the greedy algorithm mentioned in Section 3.3. In each period τ, the PMP2 selects only the combination of improvement project and process that results in the highest positive value contribution and adjusts the network accordingly. This is repeated for the desired planning horizon T. Thus, the greedy algorithm results in one instead of $(N * M)^{\tau}!$ roadmaps.

As the network dependencies and characteristics such as process-specific cash flows and lead times are case-specific input data, they are not part of the prototype. To validate the PMP2, we conducted a sensitivity analysis and a scenario analysis based on synthetic data, assuming a basic process network as shown in Figure 2. To obtain reliable results and due to low computational effort, we simulate 100,000 simulation runs. For the sensitivity analysis, we set identical input parameters for all processes regarding lead times and cash flows. We then iteratively altered individual input parameters ceteris paribus. Thereby, we observe that both positive and negative effects occur as expected, thus by decreasing cost or lead time, the network value increases and vice versa. Additionally, modifications targeting the lead times are stronger in their effect than cash flow modifications. This is due to the two-fold effect of lead time reductions. First, reducing lead time reduces the cost per network execution as cash flows are defined per time. Second, lead time reductions reduce the overall time of one network execution. Thus, within one planning horizon, the network can be executed more often, resulting in a larger quantity of outputs. As all modifications lead to the expected effect, the sensitivity analysis confirms the implemented logic of the PMP2.

To further validate the PMP2 and simulate a real-world application, we tested different scenarios based on synthetic data. In the following, we outline three cases that show how the PMP2 can assist decision makers and that stress the importance of prioritizing business processes and improvement projects in an integrated manner. To keep complexity manageable, we assume three processes according to the network depicted in Figure 2 and two improvement projects. Thereby, the projects can affect either the process-specific cash flows (project 1) or the lead time (project 2) of the improved process.

For each scenario, we provide a table which lists the most important in- and output parameters. On the far left of the tables, we depict the transition rates $\lambda_{j,k}$, which determine both the probability of making a transition from process p_j to process p_k as well as the expected dwelling times (as explained in Section 3.1). In the upper middle part, we list all cash flow-related input parameters. This comprises the process cash flows per time and process (cf_1, cf_2, and cf_3) and the value of the output created per network execution (PV). In the lower middle part, we show the relative change of the network value after the first implementation of an improvement project on a specific process. Thus, we outline the relative change from $\tau = 0$ to $\tau = 1$. We thereby list the respective process, the modification target of the project and the modification factor applied. The part on the far right shows the roadmap identified by the PMP2 based on the input parameters, a planning horizon of 5 years, and the application of the greedy algorithm.

In the first scenario (Table 4), we confirm the importance of considering process dependencies within process networks in the PMP2. If decision makers use a single process as unit of analysis, they would prioritize Process 3, as it generates the highest expected cost per instance. However, due to network effects such as higher centrality, projects improving Process 1 have a greater impact on the overall network value and should thus be prioritized. This showcases that network effects matter when compiling BPI roadmaps.

Basic Input - Trans. Rates		Dwelling time (hrs)	Transition Prob.
$\lambda_{1,2}$	0.05		0.5
$\lambda_{1,3}$	0.05		0.5
$\lambda_{1,4}$	0		0
		10	
$\lambda_{2,1}$	0.5		1
$\lambda_{2,3}$	0		0
$\lambda_{2,3}$	0		0
		2	
$\lambda_{3,1}$	0		0
$\lambda_{3,2}$	0		0
$\lambda_{3,4}$	0.2		1
		5	

Basic Input - Cash Flows			
cf_1	cf_2	cf_3	PV
-25	-150	-200	5000

Output			
Process	**Modification target**	**Modification factor**	**Relative change in %**
1	Cash flow	0.9	2.853
2	Cash flow	0.9	2.218
3	Cash flow	0.9	2.645
1	Transition rates	1.05	5.195
2	Transition rates	1.05	0.757
3	Transition rates	1.05	2.033

Roadmap		
T	***Project***	***Process***
1	2	1
2	1	3
3	2	1
4	1	1
5	2	3

Table 4: Scenario 1: Network effects matter! – analysis results

In the second scenario (Table 5), we confirm the need for looking at process networks holistically. Based on the findings from the first scenario, a decision maker would prioritize Process 1, as it has the highest centrality. However, due to the extremely high cost of Process 3, the stand-alone need for improvement outweighs the centrality. Thus, Process 3 should be prioritized to maximize the network value. This scenario demonstrates that centrality measures cannot capture all network effects and thus may lead to the misallocation of funds when used as sole unit of analysis. Therefore, it stresses that centrality is not everything and that also the stand-alone need for improvement must be considered.

For the first two scenarios, we argued from a process point of view. With the third scenario (Table 6), we put the project dimension into focus. For the first two scenarios, we assume the impact of the improvement projects to be equal, resulting in an identical modification factor. However, in a real-world use case, the impact of an improvement project might differ from process to process, depending on the prior process' efficiency. Thus, for the third scenario, we assume different modification factors representing varying impacts. Analyzing solely the project impact, improving the cash flows of Process 3 has by far the highest effect (reduction by 40%). Even if factoring in the two-fold effect of lead time reductions and thus opting for that, the decision maker would prioritize process 3, as a 20% reduction can be achieved. However, as can be seen in Table 6, conducting a 10% cash flow reduction of Process 1 is superior to all other projects. This outlines the importance of analyzing improvement projects and the underlying process network in an integrated manner, as independent analysis yields inferior results.

Basic Input - Trans. Rates		Dwelling time (hrs)	Transition Prob.
$\lambda_{1,2}$	0.04		0.4
$\lambda_{1,3}$	0.06		0.6
$\lambda_{1,4}$	0		0
		10	
$\lambda_{2,1}$	0.2		1
$\lambda_{2,3}$			0
$\lambda_{2,3}$	0		0
		5	
$\lambda_{3,1}$	0		0
$\lambda_{3,2}$	0		0
$\lambda_{3,4}$	0.5		1
		2	

Basic Input - Cash Flows			
cf_1	cf_2	cf_3	PV
-25	-120	-350	5000

Output			
Process	**Modification target**	**Modification factor**	**Relative change in %**
1	Cash flow	0.9	1.575
2	Cash flow	0.9	1.382
3	Cash flow	0.9	2.912
1	Transition rates	1.05	1.892
2	Transition rates	1.05	0.746
3	Transition rates	1.05	0.866

Roadmap		
T	***Project***	***Process***
1	1	3
2	1	2
3	2	1
4	1	1
5	2	3

Table 5: Scenario 2: Centrality is not everything! - analysis results

Basic Input - Trans. Rates		Dwelling time (hrs)	Transition Prob.
$\lambda_{1,2}$	0.04		0.4
$\lambda_{1,3}$	0.06		0.6
$\lambda_{1,4}$	0		0
		10	
$\lambda_{2,1}$	0.2		1
$\lambda_{2,3}$	0		0
$\lambda_{2,3}$	0		0
		5	
$\lambda_{3,1}$	0		0
$\lambda_{3,2}$	0		0
$\lambda_{3,4}$	0.5		1
		2	

Basic Input - Cash Flows			
cf_1	cf_2	cf_3	PV
-150	-100	-100	5000

Output			
Process	**Modification target**	**Modification factor**	**Relative change in %**
1	Cash flow	0.9	12.693
2	Cash flow	0.7	3.903
3	Cash flow	0.6	3.716
1	Transition rates	1.025	4.79
2	Transition rates	1.15	3.784
3	Transition rates	1.2	3.241

Roadmap		
T	***Project***	***Process***
1	1	1
2	2	1
3	1	1
4	1	2
5	2	3

Table 6: Scenario 3: Project impacts may be deceiving! - analysis results

By instantiating the PMP2 as a software prototype and conducting scenario analysis with synthetic data, we provide a proof of concept and demonstrate real-world applicability. The software's output contains both relative changes as well as the BPI roadmap maximizing the overall network value. Thus, decision makers can use the PMP2 to simulate, analyze and compare the effects of different improvement projects. Based on the output, optimal BPI roadmaps can be identified, and the misallocation of funds can be avoided.

5 Conclusion and Outlook for Further Research

BPI is a top priority for decision makers, with effective prioritization being a critical success factor for process improvement. Despite extensive knowledge on either the prioritization of business processes or of process improvement projects, approaches that bridge the gap between both streams yet need to be proposed. Hence, there is a need for prescriptive knowledge on how to map process improvement projects to individual business processes within process networks. Following the DSR paradigm, we developed the PMP2 that assists organizations with scheduling improvement projects while considering process dependencies in order to maximize their long-term firm value. Drawing from knowledge related to BPI, process dependencies, and VBM, we defined design objectives according to which we developed and evaluated the PMP2. Thereby, we built on MRM and normative analytical modelling. This enabled us to consider the multi-dimensional effects of process improvement projects, to cater for process dependencies, and to assess BPI roadmaps based on their contribution to the long-term firm value. We evaluated the PMP2 by discussing its features against the design objectives and competing artefacts. Additionally, we instantiated it as a software prototype based on the numerical and statistical computing environment *R*. Furthermore, we used synthetic data to simulate a real-world application and to perform a scenario analysis. Results confirm the importance of prioritizing projects and processes in an integrated manner, as the PMP2 consistently outperforms competing artefacts.

Our work contributes to research and practice. From an academic perspective, the PMP2 contributes to the prescriptive knowledge on BPI and lays groundwork at the intersection of process prioritization and the prioritization of process improvement projects. Furthermore, the PMP2 is the first to link BPI, process dependencies, project interactions, and VBM in quantitative manner. In practice, decision makers can use the PMP2 for various purposes, e.g. for analyzing the effects of different process improvement projects in a process network. Based on the model's output, decision makers can identify optimal BPI roadmaps. Practitioners can further use the PMP2 to simulate process networks and identify their value contribution. This is beneficial when setting up new process networks or when comparing network designs. Since the PMP2 builds on stochastic processes and probability theory, it is not only able to optimize the long-term firm value, but also other corporate objective functions such as quantile-based risk measures or accumulated process lead time. Hence, decision makers can use the PMP2 to optimize process networks with respect to different objectives and identify respective BPI roadmaps.

Our approach has limitations that serve as starting points for further research. As for its design specification, the PMP2 includes simplifying assumptions. As we account for process dependencies, we only do so for inter-process dependencies in terms of use and trigger relationships. Future research could extend the PMP2 to incorporate intra-process dependencies, e.g. dependencies between the performance of a process and the previous state's performance. We further assumed that parallel activities are bundled within sub-processes. Investigations on how to transfer the PMP2 into more complex process networks would provide valuable insights. Whenever increasing the real-world fidelity of the PMP2, however, future research should carefully deliberate whether an increase in closeness to reality overcompensates for the related increase in complexity. Moreover, we captured the decision makers risk attitude implicitly via a risk-adjusted interest rate. To address decision makers' risk attitude more explicitly, future research can model the value contribution's expected value and risk separately to provide further insights into the effect of risk attitudes. Following Sonnenberg and Vom Brocke (2012), we performed the evaluation activities EVAL1 to EVAL3. With the proof of concept provided in EVAL3, we laid the foundation for naturalistic evaluations based on real-world data (EVAL4). Therefore, future research should focus on further validating the PMP2 by applying it in industry-scale scenarios. Despite these limitations, our approach is an important step towards an integrated prioritization of business processes and related improvement projects in process networks.

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