Tool-based Codification in Business Process Improvement and the Impact on Problem-Solving

Florian Johannsen*,[a], Fabian Mang[b], Hans-Georg Fill[c], Sara Hofmann[d]

[a] Hochschule Schmalkalden - Fakultät für Informatik, Germany
[b] Universität Regensburg, Germany
[c] Digitalization and Information Systems Group - University of Fribourg, Switzerland
[d] University of Agder, Norway

Abstract. *Business process improvement (BPI) is an important task in times of quickly changing customer requirements and evolving technologies. A variety of BPI approaches were developed in recent years, however, the proper codification of results created in BPI projects has not been properly investigated yet. In this respect, the paper at hand examines the impact of tool-based codification approaches on problem-solving in BPI. Moreover, the effect of the design either as a spreadsheet-based or a conceptual model-based tool on user satisfaction is analyzed. For that purpose, we revert to two tools we developed, which both offer the identical functionality but diverge in the techniques of codifying results: spreadsheet templates on the one side and conceptual models on the other side. In our study, the form of codification tremendously affected the perceived user satisfaction whereas the results received for problem-solving did not show a clear preference. Regarding the former issue, the beneficial role of conceptual models for codifying results with the help of software tools could be demonstrated.*

Keywords. Business process improvement, conceptual models, modeling tool, usability

Communicated by Agnes Koschmider & Peter Fettke. Received 2020-12-02. Accepted after 2 revisions on 2022-12-03.

1 Introduction

Business process improvement (BPI) is a central task of today's companies, (cf. (Beerepoot et al. 2019; Harmon 2018; Hawkins 2018)) considering the frequently changing customer requirements and the decrease of information asymmetries between sellers and buyers caused by new digital technologies (e. g., social media, portals for product comparison, etc.) (Laudon and Laudon 2014; Mukerjee 2013). BPI deals with the change of business process elements such as "activities" or "resources" (Griesberger et al. 2011). In this respect, the "state after the change exceeds the state before the change in such a way that the degree of accomplishing organizational goals is increased, which improves the performance of the business process" (Griesberger et al. 2011, p. 3). In the domain of quality management, manifold approaches have been developed in recent years to support the execution of BPI projects (Adesola and Baines 2005; Harmon and Garcia 2020; Zellner 2011). These approaches provide procedure models (e. g., according to the Define-Measure-Analyze-Improve-Control 'DMAIC' cycle) (cf. (Snee and Hoerl 2003)), which define steps to be performed for conducting BPI projects in a structured manner. However, companies increasingly refrain from using holistic BPI approaches and prefer the pragmatic application of few selected BPI techniques (e. g., Ishikawa Diagrams, also called Fishbone Diagrams) (e. g. (Klochkov and Tveryakov 2020)) to improve their business

* Corresponding author.
E-mail. f.johannsen@hs-sm.de

processes instead (Davis 2013; Hawkins 2018; Uluskan 2016). These techniques can then be combined with traditional business process modeling and analysis approaches (Vanwersch et al. 2016; Weber and Mendling 2015).

In this regard, codification (cf. (Dalkir 2005; Hall 2006)) in BPI is crucial to enable the coordination of project teams and process improvement efforts (e. g., (Antony and Gupta 2019; Breyfogle 2010)). Codification refers to the process of converting knowledge into human- and machine-processable information (primary level of codification) (Bork and Fill 2014) but also comprises the adequate representation of the information itself, e. g., in form of conceptual models, drawings or tables (secondary level of codification) (e. g., (Anaby-Tavor et al. 2010; Hall 2006; Wand and Weber 2002)). Hence, the primary level of codification is concerned with the process of explicating previously tacit knowledge (Hall 2006); the secondary level of codification deals with the question of how to purposefully represent the information (Hall 2006). In a BPI context, the development of process improvement suggestions, based on the process knowledge of the workforce, is referred to as "primary level of codification" in the following, and the subsequent goal-oriented documentation of the improvement suggestions as "secondary level of codification".

However, "codification", and particularly the secondary level of codification, is a discipline largely neglected in BPI research (cf. (Johannsen 2017; Zellner 2011)). Whereas commonly established BPI techniques (e. g., Failure-Mode-and-Effects-Analysis – FMEA) or BPI approaches (e. g., Six Sigma) – to elicit employees' tacit process knowledge (Amaravadi and Lee 2005) for the purpose of creating improvement opportunities – can be found in literature (e. g., (Andersen 1999; Meran et al. 2013; Snee and Hoerl 2003; Uluskan 2016)) (primary level of codification), the appropriate representation of the results to be effectively communicated, analyzed and processed is not investigated properly (secondary level of codification).

In this respect, several diagram types, e. g., the Ishikawa Diagram or the SIPOC (Supplier, Input, Process, Output, Customer) Diagram, that enable the systematic representation of emerging or explicit knowledge with the help of conceptual models, are proposed in BPI literature (e. g., (Ishikawa 1980; Meran et al. 2013; Uluskan 2016)). Nevertheless, corresponding means to represent and structure the emerging knowledge in a BPI project (secondary level of codification) are not suggested for all BPI techniques alike, e. g., "process simplification" (Harrington and Lomax 2000). As a result, various approaches for representing results are used in practice, e. g., tables, lists or sketches (Anaby-Tavor et al. 2010). Considering this, the codification of knowledge in BPI projects can be efficiently supported by software, with different types of tools existing for that purpose, e. g., MS Office packages or drawing tools (cf. (Harmon and Garcia 2020)). On the one hand, software in the BPI field backs the primary level of codification by offering techniques that help to convert employees' knowledge into explicit information. On the other hand, the secondary level of codification is fostered by diagrams, tables, lists or sketches, amongst others, to present and structure the information. In practice, a huge emphasis is put on MS Excel templates, as offered by the American Society for Quality (ASQ)[1] or open access platforms (e. g., Lean Methods Group)[2] , to support the codification in BPI (e. g., (Wang et al. 2014)). Besides, also commercial tools for BPI that have purpose-built front-ends to steer user interaction and process project data exist[3] .

Against this background, little research has been done on the design of software for BPI to purposefully codify and process knowledge. Accordingly, design options for software to support users in developing and documenting process improvement opportunities have not been properly investigated yet. In particular, existing software artefacts for this purpose have so far not been evaluated in the

[1] https://asq.org/quality-resources/seven-basic-quality-tools
[2] https://www.leanmethods.com/resources/tools-templates
[3] https://www.minitab.com/en-us/products/engage/

sense of Design Science Research (DSR) (Hevner et al. 2004; Peffers et al. 2007). As a basis for the evaluation step in DSR, the theory of "cognitive fit" (cf. (Shaft and Vessey 2006; Vessey and Galletta 1991)) already indicated that the "mental representation", and hence, the way a user represents a problem in human working memory, decisively affects the emerging problem solution (cf. (Vessey et al. 2006)). According to this theory, an efficient and effective problem solution requires a consistent "mental representation" (and thus a "cognitive fit"), which is given if the "types of information" accentuated by the "problem representation" and the "problem-solving task" match (Vessey and Galletta 1991). Transferred to the BPI context a "cognitive fit" will result for instance, in case the flow of activities of a business process is to be identified and a corresponding process model – visualizing the logical arrangement of the singular activities – is used for that purpose. The graphical model directly reflects the arrangement of activities and hence, the same "types of information" in the sense of (Vessey and Galletta 1991) are emphasized by the problem-solving task and the problem representation. Contrary, a mismatch may occur in case the logical arrangement of activities is represented in form of written text with complex sentence structures, making the sequence of activities hard to identify. According to this theory, the abilities of software to represent and structure a problem may influence the effectiveness and efficiency of problem-solving. However, corresponding investigations in the context of BPI are missing.

As a step towards closing this gap, we compare two software tools for BPI that we have developed in terms of efficiency and effectiveness of problem-solving but also users' tool satisfaction in general (cf. (Bevan 1995)) by using experiments. Both software tools offer the user an identical set of BPI techniques, which have proven beneficial in practice and cover all common stages of a BPI initiative (cf. (Harrington et al. 1997; Vanwersch et al. 2016)). Each tool supports the user during the application of these BPI techniques to explicate knowledge (primary level of codification) and to document the project outcomes in a structured way (secondary level of codification). The first tool was realized as an MS Excel solution building on spreadsheet templates. Thereby, a spreadsheet template is based on a standard Excel spreadsheet that was modified to foster the development of improvement suggestions and to document the results of a BPI project. For that purpose, the user enters information into designated cells. The second tool was designed as a modeling tool and implemented via the ADOxx meta modeling platform[4] (Fill and Karagiannis 2013).

To better assess the relation between the codification of project results and the design of software for BPI, we pose the following research questions (RQ):

- **RQ1**: Which impact does the form of codifying knowledge in BPI projects – either by help of spreadsheet-based or conceptual model-based software tools – have on efficiency and effectiveness of problem-solving as well as user satisfaction?
- **RQ2**: Which insights can be derived for the theory of cognitive fit in the course of tool-supported BPI projects? In so doing, we take an important step towards a better understanding of how to design software to purposefully support codification in BPI projects.

The paper unfolds as follows: in the next section, foundations of BPI, knowledge codification and the cognitive fit theory are introduced. The tools to be analyzed and the setting of the study are dealt with in the sections to follow. Afterwards, the results of the investigation are described and interpreted. The paper ends with a conclusion and an outlook.

2 Foundations

2.1 Business Process Improvement and the BPI Roadmap

Over the last decades, manifold BPI approaches were developed (e. g., (Harmon and Garcia 2020;

[4] http://www.adoxx.org

McGovern et al. 2017)) and various research streams can be identified for this field. First, several authors propose to use employees' implicit process knowledge (Seethamraju and Marjanovic 2009) to overcome weaknesses in the design of business processes. For that purpose, they develop holistic BPI approaches that follow certain procedure models, which structure BPI projects by help of a logical arrangement of steps (phases) and supporting techniques to create results (cf. (Adesola and Baines 2005; Coskun et al. 2008; Dumas et al. 2013; Grant 2016; Harrington 1991; Noori and Latifi 2018; Palkina 2018; Povey 1998)). Thereby, "traditional" BPI techniques (e. g., Ishikawa Diagram, FMEA, etc.) (cf. (Andersen 1999; Uluskan 2016)) or certain model types (e. g., UML Use Case Diagrams, Business Process Diagrams, etc.) (cf. (Ferrante et al. 2016)) are proposed for the generation of results amongst others. A further research stream deals with the definition of "patterns" (e. g., (Alexander et al. 1977)) to support the "act of improvement" (Forster 2006) in business process management.

These patterns are seen as reusable and established instruments to reflect upon the as-is-process and derive a should-be-process (Falk et al. 2015; Lang et al. nodate; Lohrmann and Reichert 2016; Pourshahid et al. 2013; Zellner 2013). In that way, particular elements of a business process are modified (cf. (Griesberger et al. 2011; Zellner 2013)). In addition, automatic approaches for applying corresponding patterns on business process models are investigated to come to improvement suggestions (e. g., (Becker et al. 2010, 2016; Bergener et al. 2015; Smolnik et al. 2011)). An overview of business process model patterns along with a taxonomy that covers different domains is given by Fellmann et al. (2019). In this line, also the term "anti-pattern" came up, which describes counterproductive suggestions to well-recognized process problems (Koschmider et al. 2019). More, process mining (Van Der Aalst et al. 2012) has increasingly gained attention, because it enables users to compare as-is process instances with a to-be process (Măruşter and Beest 2009; Park and Kang 2016). In recent research, event logs of an as-is process are used to generate a proposition for a revised and improved process version as done by the AB-BPM methodology for instance (Satyal et al. 2019). In this respect, also the term experimental process improvement was coined, which subsumes research to enhance the BPM lifecycle by means to execute process variants (as part of experimental designs) to find potentials for process optimization (Weber and Mendling 2015). Furthermore, to systematically derive information from processes, a framework which enables the definition of contextual process querying methods was developed by Polyvyanyy et al. (2017).

Considering this variety of approaches, the BPI framework of (Vanwersch et al. 2016) is helpful to categorize use cases, which highlight the application of different BPI methods at companies. However, several authors point out that certain BPI approaches (particularly those of the first research stream) have methodological flaws, which hamper their purposeful application in BPI projects (Antony and Gupta 2019; Stojanović et al. 2016; Zellner 2011). Further, numerous methodologies are perceived as over-dimensioned by practitioners, especially for BPI initiatives with a limited scope (Davis 2013). Hence, companies often prefer to use a manageable set of selected BPI techniques for process improvement instead (Davis 2013; Hawkins 2019; McGee-Abe 2015). Because of that, we introduced the so-called BPI roadmap in a previous work (Johannsen and Fill 2014). The BPI roadmap is a sequential arrangement of a manageable set of BPI techniques that are commonly established in practice and have proven useful in BPI projects at firms of different sizes. Thereby, the BPI roadmap helps to purposefully elicit users' implicit process knowledge to generate improvement suggestions. The BPI roadmap is structured according to the DMAIC cycle (Define, Measure, Analyze, Improve and Control cycle), which is known from the Six Sigma approach (cf. (Snee and Hoerl 2003)) and comprises eleven BPI techniques. It was developed in

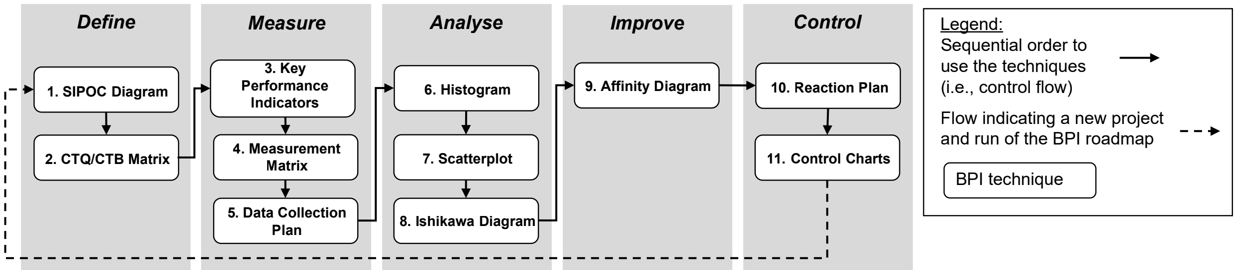


Figure 1: Business Process Improvement (BPI) Roadmap (Johannsen and Fill 2014)

cooperation with an automotive bank and evaluated in several BPI projects (Johannsen and Fill 2014). The BPI roadmap meets practitioners' current needs for pragmatic and manageable means to improve business processes (cf. (Davis 2013; Hawkins 2019)). Fig. 1 gives an overview of the roadmap. Details on each technique can be found in (Meran et al. 2013) or (George et al. 2005).

The BPI roadmap works as follows: Via the SIPOC Diagram, a business process is visualized on an abstract level. In this respect, the 5-10 most important process steps, the required input, the produced output, customers as well as suppliers of the output or the input, respectively, are pointed out. Afterwards, the expectations of customers and employees on the process performance (so called Critical-to-Quality "CTQ" and "Critical-to-Business "CTB" factors) are determined via the CTQ-/CTB-Matrix. To do so, verbally uttered customer (Voice of the Customer – VOC) and employee requirements (Voice of the Business – VOB) are condensed to core statements from which measurable project goals, namely the CTQ and CTB factors, are derived (Pande et al. 2014). In the Measure-phase, Key Performance Indicators (KPIs) – for measuring process performance – are determined, prioritized (Measurement Matrix) and corresponding measurement data is collected (Data Collection Plan). Problem causes of insufficient process performance are analyzed via Histograms and Scatterplots and structured by means of the Ishikawa Diagram. Solutions to overcome the process weaknesses are then worked out using the Affinity Diagram. Measures against the occurrence of potential process deviations are determined (Reaction Plan), and the process is continuously monitored (Control Charts). The described BPI roadmap will be processed repeatedly (indicated by the dotted arrow) and new BPI projects are initiated to consider changing customer requirements.

2.2 Knowledge Codification in BPI

The codification of knowledge in BPI projects addresses the derivation of process improvement suggestions. It is based on employees' tacit knowledge for presenting the information in a structured manner, for being efficiently communicated and further processed by machines and humans alike. Whereas we propose the abovementioned BPI roadmap as a means to support the creation of process improvement opportunities based on employees' tacit process knowledge (primary level of codification), the BPI literature gives little attention to the secondary level of codification. However, the appropriate structuring and presentation of the emerging knowledge in BPI initiatives is decisive because outcomes can be further refined and BPI projects may run in parallel (Breyfogle 2010; Seethamraju and Marjanovic 2009). However, the question of how to adequately document and structure knowledge is not sufficiently addressed by established BPI approaches. In this respect, conceptual models such as concept maps or knowledge taxonomies (Dalkir 2005) can be helpful as they do not only support people-oriented communication and understanding but also the application of technological knowledge engineering techniques, e. g., automated processing of the model content (Mylopoulos 1992).

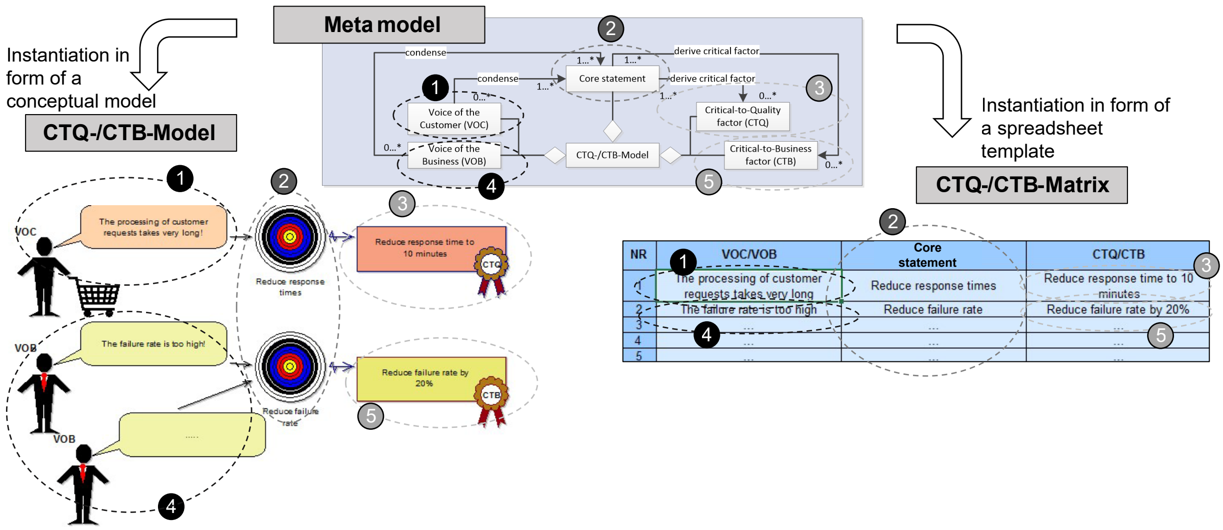


Figure 2: Meta model of the CTQ-/CTB-Matrix and instantiations as a conceptual model and a spreadsheet template

Although BPI literature offers certain diagram types, e. g., the Ishikawa Diagram (cf. (Ishikawa 1980)), which support the creation of results and clearly indicate how to arrange and structure information, corresponding presentation forms are missing for a large amount of BPI techniques. In a previous work, we thus developed conceptual model types and spreadsheet templates for the BPI techniques of the BPI roadmap to codify emerging knowledge in projects. For that purpose, the underlying functionality of each BP technique was analyzed, core concepts were derived and then transformed into classes of a meta model.

For example, the CTQ-/CTB-Matrix (cf. (George et al. 2005; Meran et al. 2013)) is characterized by the core concepts "VOC", "VOB", "CTQ", "CTB" and "Core statement". Thereby, as mentioned, the VOC and VOB statements capture the verbally uttered requirements in regard to the process performance by consumers and employees. Based on these, core statements are derived, which are used to define CTQs and CTBs thereafter (e. g., "reduce response time to 10 minutes"). In this respect, the VOC and VOB statements have to be linked to core statements and each CTQ resp. CTB factor is related to one or more core statements in turn. Consequently, the classes "Voice of the Customer (VOC)", "Voice of the Business (VOB)", "core statement", "Critical-to-Quality factor (CTQ)" and "Critical-to-Business factor (CTB)" were derived for a meta model, which defines the CTQ-/CTB-Matrix. Further, the relationclasses "condense" and "derive critical factor" were defined to specify the relationships between the classes. Fig. 2 shows the meta model as well as two exemplary instantiations. The first instance of the meta model is designed as a conceptual model and the second one as a spreadsheet template. The meta models for the other BPI techniques of the BPI roadmap with corresponding conceptual model types and spreadsheet templates were created in the same manner[5]. The applicability of the emerging model types and spreadsheet templates was demonstrated by help of data, which stems from a BPI project conducted at an automotive bank (Johannsen and Fill 2014). Further, corresponding tools were developed as described later on.

2.3 Cognitive Fit Theory

The "cognitive fit theory" was created to explain, which problem representations are most appropriate to support particular task types (Khatri et al.

[5] A link to the integrated meta model of the tool is provided at: https://tinyurl.com/zabvaw96

2006; Vessey and Galletta 1991). In this respect, the graphs versus tables controversy, and hence, the question which of these concepts to use for representing information and data was in the center of attention initially (Vessey 1991). The authors of the theory developed the notion that "complexity in the task environment will be effectively reduced when the problem-solving aids (tools, techniques, and/or problem representations) support the task strategies (methods or processes) to perform that task" (Vessey 1991, p. 220). In that case, a "cognitive fit" occurs, which increases the effectiveness and efficiency of problem-solving (Vessey 1991). In the cognitive fit model, problem-solving is the result of the interplay between the problem representation and the problem-solving task (Vessey 1991; Vessey et al. 2006). Thereby, a user formulates a mental representation, which describes the way a problem is represented in the working memory of people (Vessey 1991). The primary idea is that in case the types of information emphasized by the "problem representation" and the "problem-solving task" match, the cognitive processes used to solve a problem accentuate the identical type of information (Vessey 1991). Fig. 3 shows the general problem-solving model of the cognitive fit theory (cf. (Vessey 1991)).

According to (Vessey 1991), graphs can be seen as spatial problem representations because "spatially" related information is being presented whereas tables embody discrete data values and are entitled "symbolic representations". In this context, a further differentiation is made regarding "spatial" and "symbolic" tasks (cf. (Vessey 1991; Vessey and Galletta 1991)). Thus, spatial tasks require the user to make or perceive associations in the data, with perceptual processes being most appropriate for solving these tasks and coming to a "cognitive fit" (Vessey 1991). Contrary, symbolic tasks lead to a precise data value and are best performed via analytical processes that extract and act on discrete data values (Vessey 1991). Thereby, (Vessey and Galletta 1991) show that users tend to formulate a mental representation of the problem, which is consistent with the type of information in the first problem-solving element considered. Hence, when a spatial task is given, users create a mental representation of the problem that associates relevant data for solving the task (cf. (Vessey and Galletta 1991)).

The above-shown basic model was modified in literature, e. g., by Zhang and Norman (1994) who differentiate between an internal representation of the problem domain and an external problem representation. (Shaft and Vessey 2006) distinguish between mental representations for software and maintenance tasks in the context of software maintenance. (Larkin and Simon 1987) suggest to differentiate between the task types "search" (e. g., search for an information), "recognition" (e. g., recognize unveiled inferences) and "inference" (e. g., identify new inferences, not explicitly described yet). Further, (Vessey and Galletta 1991) propose to consider "individual problem solver characteristics" as a further element to impact the "mental representation". Therefore, they enhance the above basic model by users' "problem-solving skills", which describe particular procedures a person uses to solve a problem (Vessey and Galletta 1991).

In the BPI context at hand, conceptual model types, as described in the preceding section (e. g., CTQ-/CTB-Model), produce "spatial representations" of information because quality-related concepts (e. g., VOC/VOB statements or CTQ/CTB factors) are represented by modeling constructs that are put into relation. Contrary, information captured in spreadsheets (e. g., data for the Data Collection Plan) represents a "symbolic representation" of knowledge emerging in BPI projects. Transferring the proposition of (Vessey and Galletta 1991) to the context at hand, the creation of a "mental representation" for a BPI-specific problem in the working memory of a user (cf. (Vessey 1991; Vessey and Galletta 1991)) could thus be influenced by both, conceptual models types as well as spreadsheet templates that are used to codify ideas. In this regard, spreadsheet-based or conceptual model-based tools serve as problem-solving aids (cf. (Vessey 1991)) to work on a problem-solving task occurring in BPI projects (e. g., derivation

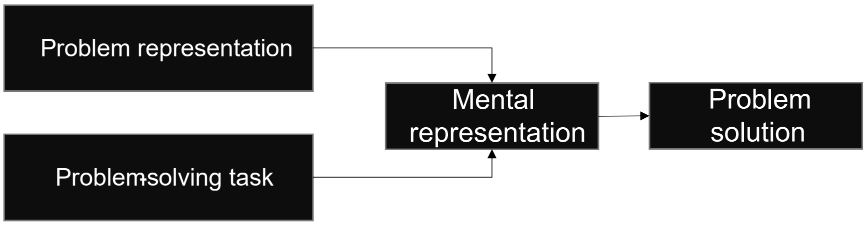


Figure 3: General Problem-Solving Model according to the Cognitive Fit Theory (Vessey 1991)

of customer requirements). Hence, the question is, whether the design of a software – either as a spreadsheet-based or conceptual model-based tool – influences the effectiveness and efficiency of problem-solving in BPI as well as users' general satisfaction with the software.

Generally, various forms of codification such as cognitive maps, knowledge taxonomies, decision trees, tables or sketches are discussed in knowledge management literature (cf. (Anaby-Tavor et al. 2010; Dalkir 2005)). In the context of BPI, especially spreadsheet templates have a wide distribution, which is due to the availability of MS Excel-based solutions (see Sect. 1) and MS Office packages in general. Additionally, conceptual models represent a promising means for codification purposes because they visualize relations between input and output information (e. g., customer requirements and quality goals) supporting people-oriented communication in BPI (e. g., (Hagemeyer et al. 2006; Mylopoulos 1992)). Accordingly, conceptual models and spreadsheet templates are in the center of our study. Moreover, since the application of the cognitive fit theory in the BPI discipline is an under-researched topic yet, we approach this field by focusing on the "problem solution" element in a first step as well as corresponding measures for its quantitative assessment.

2.4 Measurement of Effectiveness, Efficiency and User Satisfaction

According to the cognitive fit theory, the used problem-solving aids influence the effectiveness and efficiency of problem-solving (e. g., (Vessey and Galletta 1991). In literature, effectiveness of problem-solving is often measured by help of true/false, multiple choice or open questions (cf. (Burton-Jones and Meso 2006; Vessey 1991; Vessey and Galletta 1991)). However, since we focus on tool-based approaches for codifying knowledge in BPI, we revert to effectiveness measurements encountered in the field of software usability. In this respect, effectiveness in performing a particular task (task effectiveness), e. g., identification of problem causes, is typically judged on the base of the output completed (e. g., 50% of the previously defined task) as well as the quality of the output (e. g., degree to which the output achieves aspired goals) (Bevan 1995; Kirakowski 1998). Take the task of formulating CTQ or CTB factors, which is commonly executed in BPI projects (e. g., (Pande et al. 2014)). On the one hand, task effectiveness would then refer to the question of whether all relevant customer and employee requirements (VOC and VOB statements) have been considered or not (output completed). On the other hand, the quality of the CTQ and CTB factors would be in the focus, e. g., whether these have been specified in a measurable manner or not (quality of the output).

As (Vessey 1991) states, time measurements have played a minor role in table and graph research. However, considering research in the field of software usability, a common measure to determine efficiency is the so-called "temporal efficiency". Temporal efficiency relates the variables "task effectiveness" and "task time" to one another (temporal efficiency = task effectiveness/task time) (Bevan 1995). Thereby, task time captures the timespan for completing a certain task. In this respect, the time required for working on a task is put into relation to the "task effectiveness" and, hence, efficiency-effectiveness trade-offs are considered (cf. (Bevan 1995; Vessey 1991)).

Since software-based approaches supporting the codification of knowledge in BPI are in the focus of this research, user satisfaction with the software under investigation is a further highly relevant perspective. The measurement of user satisfaction is a subjective undertaking and, thus, standardized questionnaires were developed in recent years to enable an assessment, e. g., the SUMI (Software Usability Measurement Inventory) questionnaire or the ASQ (American Society for Quality) approach (Sauro and Lewis 2012). In this context, the SUMI questionnaire has established as a widely recognized approach for testing user satisfaction (Mansor et al. 2012) and was created and validated on a Europe-wide basis (Veenendaal 1998). It comprises the quality dimensions "efficiency", "affect", "helpfulness", "control", and "learnability" that are assessed using 50 questionnaire items (e. g., "tasks can be performed in a straight forward manner using this software") (cf. (Kirakowski and Corbett 1993)). A key advantage of the SUMI questionnaire is that "efficiency" is one of the five quality dimensions (cf. (Kirakowski and Corbett 1993)), which is assessed on base of certain questionnaire items (e. g., "tasks can be performed in a straight forward manner using this software"). Hence, the application of the SUMI questionnaire offers a further, though subjective, approach for measuring "efficiency" besides the abovementioned "temporal efficiency" measure.

3 Software Tools for the BPI Roadmap

In this section, the development of both tools that serve the comparison of spreadsheet-based and conceptual model-based codification approaches in BPI is briefly described.

3.1 Design Science

Both tools were developed by help of the DSR approach (Hevner et al. 2004; Peffers et al. 2007). In DSR, researchers make use of knowledge related to tasks or situations to arrive at artifacts to solve practical problems (March and Smith 1995). An artifact is a "human-made object, in contrast to a natural object" (Goldkuhl and Karlsson 2020, p. 1241) and can take the form of algorithms, methods or software for instance (Peffers et al. 2007). To structure DSR efforts, the relevance, rigor and design cycle have been introduced by Hevner (2007). While the relevance cycle serves the identification of requirements by considering the application context, the rigor cycle reflects upon the innovativeness of the artifact by querying the scientific body of knowledge (e. g., existing experiences, expertise, etc.) (Hevner 2007). The design cycle deals with the iterative construction and evaluation of the artifact (Hevner 2007). However, besides the artifact – as an outcome of a DSR project – its implications to existing theories should be focused as well (Baskerville et al. 2018).

Various suggestions have been made on the process of constructing DSR artifacts (e. g., (Peffers et al. 2007; Vashnavi and Kuechler 2004)). For instance, (March and Smith 1995) differentiate between the major steps "build", "evaluate", "theorize" and "justify". Thereby, the theorizing step searches for explanations for a change in performance that is triggered by the interaction between the artifact and its environment (March and Smith 1995). The validity of the theoretical assumptions is then to be validated in the justify step (March and Smith 1995). In addition, (Peffers et al. 2007) proposed a six step-procedure (identify problem and motivate, define objectives of a solution, design and development, demonstration, evaluation, communication), which combines generally acknowledged process elements that guide DSR efforts. Thereby, the approach was developed in a consensus-building manner (Peffers et al. 2007) and served as a base for building both tools in our research. To sum up, besides the construction of an artifact, its contribution to theories should be discussed in a DSR project (Baskerville et al. 2018). The paper at hand covers aforementioned perspectives, because the created software tools for BPI are reflected against the cognitive fit theory later on.

3.2 Objectives of a Solution

Before building tools to support the application of the BPI roadmap, the objectives are to be specified considering the problem definition and knowledge about the feasibility (Peffers et al. 2007). The purpose is to define requirements an artifact should meet to fulfill users' needs (cf. (Peffers et al. 2007)). Therefore, interviews with practitioners of a German automotive bank – who are strongly engaged in BPI activities in their daily routines – were conducted and 17 functional and non-functional requirements determined[6] .

In this context, the first tool to support the transformation of employees' implicit process knowledge into process improvement suggestions (primary level of codification) – was supposed to build on MS Excel and visualize the results by help of spreadsheets (secondary level of codification). It thus represents a technical solution often met in BPI projects in practice. The second tool ought to use conceptual models for structuring and representing the results of a BPI initiative (secondary level of codification). For that purpose, the metamodeling platform ADOxx was chosen to realize the corresponding modeling tool. Considering these diverging technical platforms (MS Excel and ADOxx), proprietary requirements arose on each tool, which were non-functional in nature. Tab. 1 shows an excerpt.

3.3 Design and Development

Before starting the implementation process, a data model as well as meta models for the BPI roadmap were created and the input information received as well as the output information produced by a BPI technique (cf. (Hagemeyer et al. 2006)) were specified in detail.

For the creation of the first tool (MS Excel solution), spreadsheet templates were designed enabling to document and represent the results received by applying the BPI techniques. The processed data was thus supposed to be directly stored in worksheets. The menu navigation, a graphical front-end as well as the dynamic aspects of the tool (e. g., functional requirements #3 or #5 in 1) were realized via Visual Basic for Applications (VBA). Statistical techniques, e. g., histograms and scatterplots, could be easily implemented due to the data analysis functionality offered by MS Excel. For implementing the second tool in the form of a modeling software, the ADOxx meta modeling platform was used (cf. (Fill and Karagiannis 2013)). Meta modeling platforms offer huge benefits for realizing software support because classes and relations can be largely implemented without programming efforts, and an environment for the storage, user interaction and the generation of models is provided automatically amongst others (cf. (Clark et al. 2008; Fill and Karagiannis 2013)). Generally, ADOxx has been beneficially applied in practice and science for more than 20 years now and has constantly been further developed (Fill and Karagiannis 2013). For the realization of the tool, the conceptual model types designed for the techniques of the BPI roadmap were referred to (see Sect. 2.2) (Johannsen and Fill 2017). To enable the statistical analyses of process data and the generation of statistical diagrams (e. g., histograms, scatterplots), an interface to the statistical software *R* (www.r-project.org) was established (Fill and Johannsen 2016).

3.4 Demonstration

To demonstrate the applicability and usefulness of both tools (cf. (Hevner 2007; Peffers et al. 2007)) to process and analyze data, the datasets stemming from various BPI projects conducted in cooperation with a German automotive bank were referenced. Therefore, it was checked whether the real-life data could be seamlessly documented and processed (i. e., statistically analyzed) by both tools[7] . Furthermore, the tools are continuously evaluated with diverse practice partners to gather feedback and develop them further.

[6] The complete list of requirements is provided in the supplementary material: https://tinyurl.com/zabvaw96

[7] Tool II (modeling tool) is available at: https://austria.omilab.org/psm/content/rupert/download?view=download (Version 2.0) A short video about tool I (Excel solution) can be viewed at: https://tinyurl.com/4nu9rsr4

Examples for functional requirements			
#1	Support of the BPI techniques of the BPI roadmap and means to codify the results.		
#2	Option to select particular BPI techniques and apply singular techniques.		
#3	Availability of further help information about each BPI technique.		
#4	Printing option for the results produced by applying the BPI techniques.		
#5	Automated data transfer between BPI techniques, i.e., output created via a technique that serves as input to a subsequent technique should be automatically transferred.		
…			
Examples for non-functional requirements			
#11	Easy and self-explanatory installation of the tool.		
#12	High learnability of the tool.		
#13	Fast response times for statistical analyses of project data (e.g., via histograms, control charts).		
…			
Proprietary non-functional requirements (MS Excel solution – tool I)		**Proprietary non-functional requirements (modeling tool – tool II)**	
#1	Tool must be executable using MS Excel versions 2010 and newer.	#1	Option to draw upon a locally installed SQL server.
#2	Clearly arranged front-end using the script language VBA.	#2	Executable on the operating system Windows 7 or newer.
…		…	

Table 1: Exemplary overview of requirements

Fig. 4 shows screenshots of the tools. In this regard, a SIPOC Diagram, an Ishikawa Diagram as well as a Measurement Matrix are presented for each tool (see also Fig. 1). By that, differences regarding the secondary level of knowledge codification via spreadsheet templates (tool I) and conceptual models (tool II) become immediately apparent for the Measurement Matrix and the SIPOC Diagram.

In this respect, tool II offers modeling constructs for each core concept of a BPI technique (e. g., Supplier, Process steps, Customer, Input and Output for the SIPOC Diagram), which are used for the creation of conceptual models. In tool I, the corresponding information is entered into pre-defined spreadsheet templates and is arranged in rows and columns of a worksheet. However, besides the documentation of information, also the primary level of codification and, hence, the explication of tacit knowledge may be affected. Thereby, knowledge is mapped to spatial or symbolic representations of a task/problem in the working memory of the user (cf. (Vessey and Galletta 1991)). It is to be examined whether problem-solving is affected, by either demanding users to shape their ideas in form of conceptual models, or to fill out pre-defined templates. That way, insights can be gained on whether the design of a tool as a spreadsheet-based or conceptual model-based software (problem-solving aids) influences the effectiveness and efficiency of problem-solving in BPI as well as users' tool satisfaction. In BPI projects users are often confronted with spatial tasks, whereby input information is purposefully transformed to output information by help of BPI techniques (cf. (Hagemeyer et al. 2006)). Accordingly, it could be hypothesized that tool II performs better than tool I in terms of efficiency and effectiveness of problem-solving as well as user satisfaction.

Both tools were developed by following the DSR process of (Peffers et al. 2007) as described above. The design and development stages built on the functional and non-functional requirements as shown in Tab. 1 to arrive at tool-support for the BPI roadmap (see Sect. 2.1). However, due to the different platforms used, some proprietary requirements arose for each tool regarding the technical realization (Tab. 1). We argue that both tools are prestigious representatives for codifying knowledge in BPI. On the one hand, several quality institutions (e. g., ASQ, Lean Methods Group, etc.) offer templates for BPI techniques that are based on MS Excel (see Sect. 1), while many companies use MS Office in the course of process analysis and improvement efforts (cf. (Harmon and Wolf 2011; Villanueva 2021)). This circumstance is acknowledged by tool I, which is realized

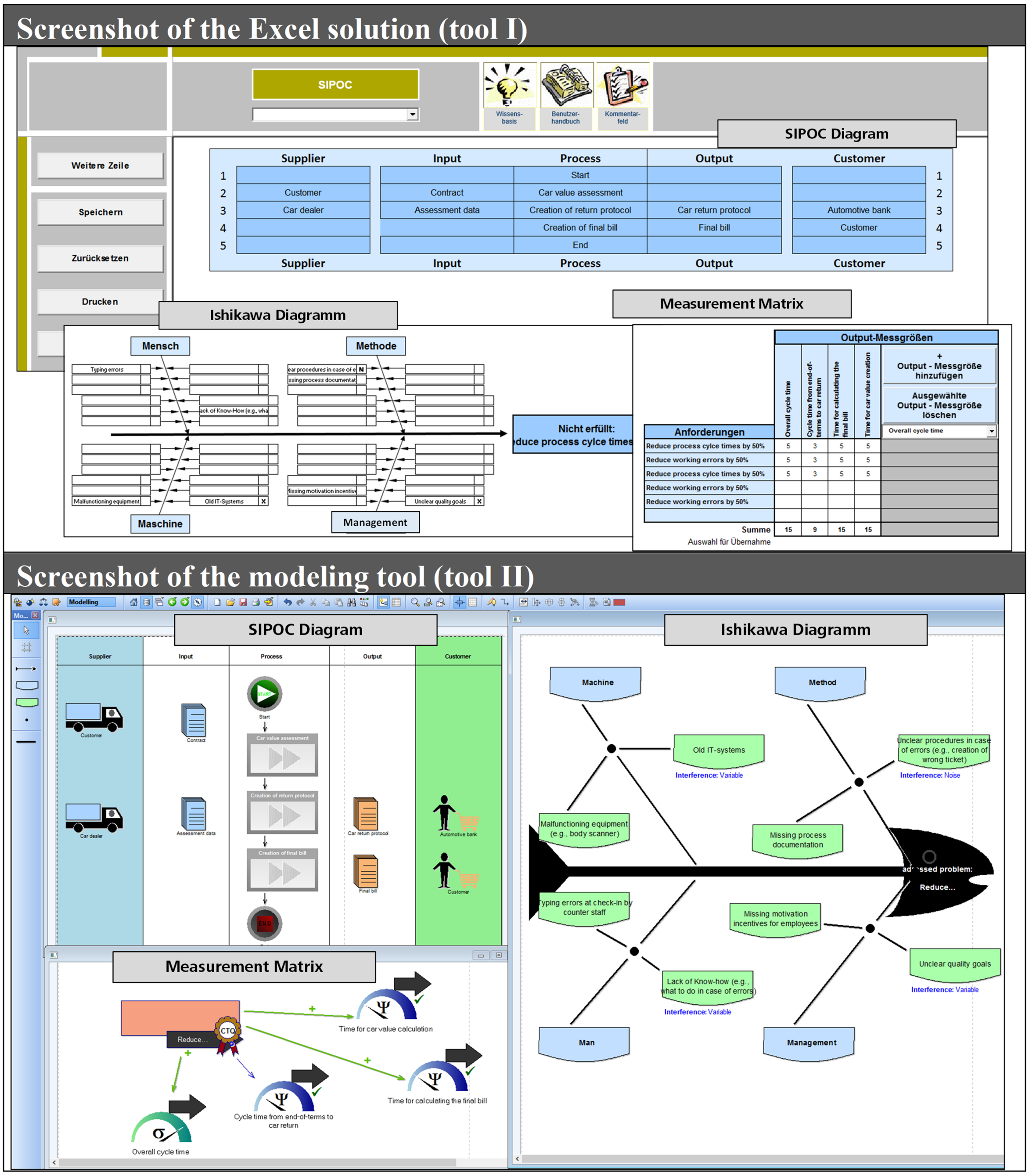


Figure 4: Screenshots from both tools

as a MS Excel solution. As a distinctive feature, our tool integrates different templates into one solution and enables an automatic data transfer between these. On the other hand, various model types and graphical representations have been developed to codify and document project results in BPI, e. g., the Ishikawa Diagram or SIPOC Diagram (cf. (Meran et al. 2013)). Furthermore, well-known modeling techniques like the Unified Modeling Language (UML) or the Business Process Model and Notation (BPMN) are applied in BPI projects as well (cf. (Ferrante et al. 2016)). Thereby, the graphical representations increase understanding for the problem domain and facilitate the communication of results (Anaby-Tavor et al. 2010). As a consequence, also modeling tools are frequently used in BPI projects (cf. (Harmon and Garcia 2020)). Considering this, the techniques of the BPI roadmap were transformed into model types and a corresponding modeling tool (tool II). The aforementioned forms of codification as offered by tool I (spreadsheet-based templates) and tool II (model types) are also combined by some commercial tool providers (e. g., Minitab).

4 Materials and Experiment Conduction

4.1 Case Studies and Measurement of Effectiveness, Efficiency and User Satisfaction

In total, two laboratory experiments (cf. (Wohlin et al. 2012)), based on two case studies, were conducted with 32 Master's degree students of Management Information Systems (MIS) at a German university. Thereby, each student attended a course on "quality management" dealing with the fundamentals of BPI and took part in both experiments. The students can thus be regarded as proxies for practitioners in business process improvement since they have received dedicated training in business process improvement methods. Students of this type have been previously found to be adequate as proxies for practitioners on novice level so that no previous background knowledge has to be considered (Gemino and Wand 2004; Parsons and Cole 2005).

Case study 1: The material of the first experiment was a fictitious case study dealing with the check-in procedure at an international airport. In short, the fictitious process was as follows. *As soon as a passenger arrives at the airport the baggage is dropped at the check-in counter. Then, the passenger is handed over the boarding pass by a service employee. After passing the security check the passenger boards the aircraft.*

Against the background of the case study, the participants of the experiment were asked to develop suggestions for process improvement using the tools. For that purpose, the case study presented a list of fictitious passenger and service employee statements, indicating current process performance problems (e. g., "the security check takes very long"), as well as corresponding measurement data (e. g., cycle times) as proof.

Case study 2: A second case study – dealt with in the second experiment – was based on a real BPI project conducted in cooperation with an automotive bank focusing on the end-of-leasing-contract (EOLC) process. *The EOLC process is triggered as soon as a customer's leasing contract ends. The car dealer then assesses the current car value and creates a car return protocol (CRP). This CRP is used by the automotive bank to generate the final customer bill. The process ends as soon as the customer meets the bill.*

Again, current problems of the process were unveiled by employee and customer statements as well as corresponding measurement data. The tools were to be used by the participants for developing process improvement opportunities.

To assess the influence of conceptual model-based and spreadsheet-based tools (problem-solving aids) on the effectiveness and efficiency of problem-solving in BPI, abovementioned measures "task effectiveness" and "temporal efficiency" were used. These measures have been established in software usability studies and are widely acknowledged (cf. (Bevan 1995)). For measuring the task time (to be able to determine the temporal efficiency), participants were supposed to indicate the time (minutes) they required for completing a case study. Both case studies ("check-in at airport" and "EOLC process") consisted of four tasks each. For each task, the participants were asked to precisely note the time required for completion. To create a realistic BPI scenario, the tasks required users to process input information to output information by help of BPI techniques. To judge the task effectiveness (cf. (Bevan 1995)) both, the quality and quantity of the submitted solutions were to be rated. Therefore, the results of the case studies were to be submitted to the authors of this study electronically.

Generally, BPI initiatives may be large in scale, while in our experiments, participants were asked to perform few tasks only. This is explained as follows. First, there is the tendency to narrow the scope of BPI projects to quickly react to changing market environments these days (Davis 2013). As a result, the concept of "agility" from software engineering is becoming increasingly popular in BPI as well (Hofmann 2020). Hence, projects are planned in form of "process sprints", in which a limited set of goals should be achieved within a narrow time frame (Hofmann 2020; Stoesser 2019). The term "sprint" was adopted from the SCRUM method (Hofmann 2020; Sutherland and Schwaber 2007). To realize the objectives of a sprint, few selected BPI techniques come to use to solve a specific problem, a situation that is simulated by our experiments. Thereby, several sprints may be required to create fundamental changes in a business process (Hofmann 2020). Second, certain stages of a BPI project seem to be more challenging and critical for project success than others (cf. (Johannsen et al. 2011; Kettinger et al. 1997)). Hence, using data-driven performance measurements and getting a clear picture of stakeholder requirements, processes and a company's environment are considered as decisive prerequisites to systematically derive performance improvement goals (cf. (Lückmann and Feldmann 2017; McAdam and Donaghy 1999; Trkman 2010)). However, firms obviously struggle with exactly these tasks (cf. (Johannsen et al. 2011)) and BPI initiatives may thus stay behind expectations. We argue that tool-support and a proper codification of results is especially relevant for these activities and hence, put them in the center of our case study material.

Since software-based solutions to support codification are in the center of attention, also user satisfaction with the tools was measured. In this context, it is the combination of objective measurements, such as abovementioned efficiency and effectiveness, with subjective usability or user satisfaction ratings that determine users' experience with a software product (Diefenbach et al. 2014; Lewis 2018). This aspect is important for DSR, because software that is perceived as highly aesthetic is often judged to be usable and helpful at the same time (Ben-Bassat et al. 2006; Norman 2004). Hence, users may assign a superior usability to a specific tool even if the measured performance is lower to competing products (Ben-Bassat et al. 2006). Therefore, it is interesting to see whether this observation is given for our BPI tools too. Hence, important feedback is gained by the measurement of usability to further improve the tools.

To measure usability, the abovementioned SUMI questionnaire (cf. (Kirakowski and Corbett 1993)) was applied. The SUMI questionnaire was developed by the Human Factors Research Group (HFRG) at the University College Cork. It builds on 50 different items (e. g., "I feel in command of this software when I am using it") with Likert-scales being used for rating each item ("agree", "disagree" and "undecided"). Besides the dimensions "efficiency", "affect", "learnability", "control" and "helpfulness", the construct "global scale" provides information on a software's general usability and is based on 25 selected items (Veenendaal 1998). A major strength of SUMI is that a normative database (comprising approx. 150 software applications) is used for analyzing and interpreting the results gained by applying the SUMI questionnaire (Sauro and Lewis 2012). Furthermore, "efficiency" is one of the five quality dimensions that is assessed by users' subjective perception complementing the perspective on temporal efficiency. The SUMI questionnaire was thus chosen as a means to determine user satisfaction.

In summary, the measures "task effectiveness", "temporal efficiency" as well as the SUMI approach were used to assess the effectiveness and efficiency of problem-solving performance in BPI as well as a user's satisfaction regarding the tool. Accordingly, the material in each experiment comprised the corresponding case study, a form sheet on which to note task times (to determine the temporal efficiency) and the SUMI questionnaire. The solutions were then handed in by e-mail and were rated by two researchers (task effectiveness). A pre-test was performed with 33 Master's degree students in economics at an Austrian university and the received results confirmed the suitability of the material for the study at hand[8] .

4.2 Experiment Conduction

The first experiment (*experiment 1: case study "check-in at airport"*) was conducted after the first half of the course "quality management" and the second experiment (*experiment 2: case study "EOLC process"*) was performed towards the end of the course. Each of the aforementioned 32 students of MIS at a German university took part in both experiments. In this regard, the set of participants was randomly split into two groups. The first group comprised 15 (group A) and the second group 17 students (group B). In the first experiment, group A worked with the modeling tool (tool II) to solve the case study and group B used the Excel solution (tool I). In the second experiment, the assignment of the tools to groups A and B was switched. Thus, after completing the experiments, each participant had worked with both tools. A major advantage of the SUMI approach is that only a minimum number of 10-12 participants is required to come to a valid analysis (http://sumi.uxp.ie/about/sumipapp.html). In our experiment, we exceeded this number of participants.

In each experiment, the participants were handed out the material on paper. Because SUMI requires the users to have some experience with the tool to be evaluated (cf. (Veenendaal 1998)), the participants received an introduction to the tools as well as a tutorial. The students were supposed to solve the case studies on their own and make proposals for improving process performance. Each experiment was supervised by two researchers. Extra credits for the course "quality management" could be earned by the students, an incentive to take the study seriously (cf. (Wohlin et al. 2012)). The submitted solutions were then screened and rated by two researchers regarding the quantity and quality of the tasks. Similar to written exams, the tasks were allotted points. More precisely, the submitted results were judged by each rater considering completeness, correctness and the fulfillment of technique-specific quality criteria (the students were introduced to throughout the course). This enabled an objective assessment to the greatest extent as possible. However, in case of differing ratings, a discussion between the raters was planned to assure interrater-agreement (cf. (Hayes and Krippendorff 2007)). Both tools were developed by the author team over a considerable amount of time, and hence, a preference for a tool (e. g., (Lacy 2001)), which may have influenced the objective rating of the submitted solutions could be excluded.

Completeness referred to whether a task was completely solved or some parts were missing. For instance, in experiment 1, a SIPOC Diagram was considered as incomplete in case the problem domain (as described in the text) was not fully covered by the diagram. As a further example, an incomplete CTQ-/CTB-Matrix would be given if some VOC statements were neglected. Correctness referred to the accurate representation of the problem situation (cf. (Lindland et al. 1994)), e. g., whether obvious facts were wrongly interpreted or not. In this respect, an error could be the incorrect arrangement of activities in a SIPOC Diagram or the misinterpretation of a CTQ factor as a CTB factor for instance. In addition, quality criteria that are specific for certain BPI techniques exist. These were introduced to students throughout the course "quality management" and were supposed to be

[8] The material can be accessed at: https://tinyurl.com/yvxjfynn

applied by them when working with techniques. For instance, the SMART criteria (Specific, Measurable, Achievable, Relevant, Time-based) are widely used to assure the measurement and adequacy of CTQ and CTB factors (cf. (Bjerke and Renger 2017; Meran et al. 2013)). Accordingly, the project goals associated with CTQ and CTB factors should be achievable and linked to measurable target values amongst others. Moreover, problem causes documented in an Ishikawa Diagram should be assigned to categories and further specified by help of the "Five-Whys" to arrive at more fine-granular results (cf. (George et al. 2005; Ishikawa 1980)). It is to be mentioned, that constraints implemented in the tools prevented users from making syntactical errors (cf. (Lindland et al. 1994)). Since the focus of the experiments was on the problem-solving process, the practical applicability of the derived improvement suggestions regarding effectiveness on process performance or net-benefits was not evaluated.

Contrary to the solutions of the case study, the submitted SUMI questionnaires were anonymized. This was done to mitigate participants' concerns about negative consequences in case of poor ratings for the tools. All participants submitted completed SUMI questionnaires in both experiments and were greatly committed to produce convincing results due to the opportunity to receive extra credits. Thus, all submissions could be used for the upcoming analysis. The data from the SUMI questionnaires was entered into the official SUMI online form (http://sumi.uxp.ie/en/index.php) and the results of the usability study were made available by the HFRG afterwards (see RQ 1).

4.3 Analysis of the Data

The results from the SUMI questionnaires were analyzed in an aggregated form for each tool. That means the solutions for the case studies as well as the SUMI questionnaires received for tool I (MS Excel solution) from the first and second experiment were used together for gaining an overall assessment for the tool (effectiveness, efficiency and user satisfaction). The same holds true for judging tool II (modeling tool). This was done to consider the potential influencing factors "problem-solving skills" in BPI and "technology affinity". Thus, if a group A or B was considerably more technographic and more skilled in dealing with situations encountered in BPI projects (cf. (Vessey and Galletta 1991)) than the other group, the overall ratings received for tools I and II would not be comparable when considering one experiment only. By the aggregation across the experiments, this circumstance is considered. Further, considering two case studies enables a more nuanced assessment of effectiveness, efficiency and user satisfaction, because results are not imprinted by one particular scenario (case study) only. In this respect, the general comparability of the tools and their suitability for solving the case studies are assured because they were developed on the base of a common set of requirements as explained in Sect. 3.

To estimate the impact of tool II on the time needed for solving the case study, the effectiveness, and the temporal efficiency, a multilevel regression analysis was conducted. We estimated the following estimation equation:

$$Y_i = \alpha + \beta * \text{case\_study}_i + \gamma * \text{group}_i + \delta * \text{rupert}_i + \epsilon_i \tag{1}$$

Y_i is the respective outcome variable for student i, case_study is a dummy variable that equals one for experiment 2 and zero otherwise, group is a dummy variable that equals one for the student group A and zero for group B, rupert is a dummy variable that equals one if a case study was worked on with the help of tool II, and ϵ_i is an ideosyncratic error term. The regression analysis thus estimates the impact of working with tool II while considering the fact that students in both groups may differ in their ability and that different case studies may differ in their difficulty.

5 Results and Interpretation

In this section, the results of the analysis are presented considering the measurements "task effectiveness", "temporal efficiency" and "user satisfaction". The results are interpreted afterwards.

5.1 Results

Task effectiveness & temporal efficiency: The task effectiveness was generally high in both experiments (see descriptive analysis in Tab. 2). While tool II performed slightly better in experiment 1, its task effectiveness was slightly lower in experiment 2. In terms of efficiency as measured in task time required for the experiments, tool II was superior in experiment 1 while tool I was more efficient in experiment 2. Regarding temporal efficiency, which is calculated as effectiveness per task time, tool II outperformed tool I in experiment 1 whereas tool I had a higher temporal efficiency in experiment 2.

The regression shows that students on average needed 10.4 minutes more to finalize their case study (p-value 0.14) when they used tool II (controlling for group and case study) (see Tab. 3). In addition, we found that students using tool II were on average 0.34 percentage points more effective in their case study (p-value 0.64), again controlling for group membership and case study. Regarding the temporal efficiency, the regression shows that the temporal efficiency of students using tool II was lower by on average 0.21 percentage points per minute (p-value 0.04).

The regression analysis also indicates the strong effect of the group as well as the experiment. Group A was significantly faster by 32 minutes on average (p-value 0.001) while the effectiveness results for case study 1 were significantly better by 2.9 percentage points (p-value 0.000).

User satisfaction: The SUMI reference database suggests an average score of "50" for each SUMI dimension and the "global usability" (Veenendaal 1998). Considering this, a positive overall user satisfaction resulted for tool II (global score mean: 53.78; median: 56.5), which however, does not hold true for tool I (global score mean: 43.56; median: 42.5) (see Tab. 4).

Especially regarding the dimensions "efficiency" and "affect", tool I performed significantly worse than tool II. This is surprising since a gap can be observed considering the perceived "efficiency" as outlined by the results of the SUMI analysis and the calculation for temporal efficiency for tool I in experiment 2. Generally, users of the Excel solution (tool I) did not feel well-supported by the tool when working on the case studies (efficiency) and their emotional attitude towards the tool was low (affect) according to the SUMI results. Further, the participants rated the efforts to be made for learning to handle tool I as average (learnability), a rating also given for the tool's ability of being self-explanatory (helpfulness). The score for "control" was slightly below the score of "50". By contrast, the results for tool II (modeling tool) were above the average score of "50" for almost all dimensions. Users perceived the tool to be supportive for conducting the case studies (efficiency) and self-explanatory at large (helpfulness). It did not behave in an unexpected manner (control) and the efforts required for learning to handle the tool were manageable (learnability). An average emotional attitude towards the tool was observed (affect). The statistical variance and confidence intervals were smaller for tool II than for tool I, i. e., the degree of agreement among users was higher. Furthermore, the SUMI questionnaire asks for user's software skills and knowledge (item "How would you rate your software skills and knowledge?") using a four-point Likert scale ("I find most software difficult to use", "I can cope with most software", "I'm good but not very technical", and "Very experienced and technical") (cf. (Kirakowski 1998)). Group A had a slightly higher mean value than group B, which however was statistically not significant.

5.2 Interpretation of the Results

The results are initially interpreted and discussed in light of effectiveness, efficiency and user satisfaction as stated in the first research question (see RQ1).

Effectiveness: First, considering effectiveness, the regression analysis indicates that working with tool II (conceptual model-based software) leads to slightly better results. This can be an indicator that conceptual models – and hence, conceptual

Effectiveness				
	Excel solution (tool I)		**Modeling tool (tool II)**	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Task effectiveness [%] – mean value	95.11%	99.66%	97.06%	98.41%
Efficiency				
	Excel solution (tool I)		**Modeling tool (tool II)**	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Task time [minutes] – mean value	88.50	62.13	66.93	104.53
Temporal efficiency	1.07	1.60	1.45	0.94

Table 2: Results for Efficiency and Effectiveness

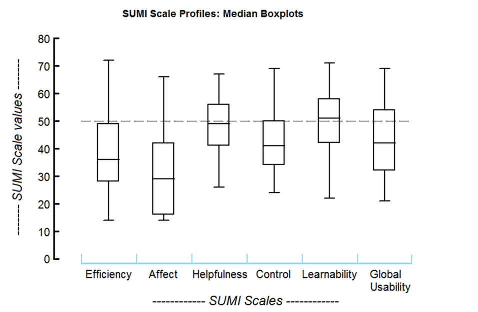
Variables	Efficiency	Effectiveness	Temporal efficiency
case_study	5.61 (6.90)	2.94*** (0.74)	0.07 (0.10)
rupert	10.41 (6.90)	0.34 (0.74)	-0.21** (0.10)
group	-31.98*** (8.82)	1.60 (0.94)	0.50*** (0.12)
constant	88.5*** (8.43)	95.11*** (1.34)	1.23*** (0.11)
R-squared	0.2280	0.2011	0.2794
N	64	64	64

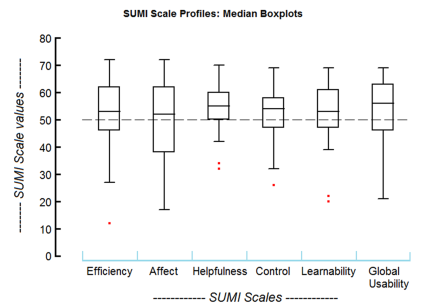
Table 3: Effects of using tool II (Rupert) on effectiveness, efficiency and temporal efficiency

model-based software tools – help in creating mental representations (cf. (Vessey 1991)) in regards to the problem situation, to purposefully support problem-solving in a BPI setting. However, it needs to be noted that the effect is not statistically significant in our study. In addition, at a more fine-grained level, neither the use of conceptual models (tool II) nor spreadsheet templates (tool I) was superior for the creation of a CTQ-/CTB-Matrix in experiment 1 (task 2) in regards to the points scored (see Sect. 4.2). In contrast, in experiment 2, the group using the spreadsheet-based tool (tool I) slightly scored better than the participants using tool I for establishing a CTQ-/CTB-Matrix (task 1). This is surprising, because particularly this task calls for the cognitive process of "inference" (Larkin and Simon 1987) to identify relationships between VOC and/or VOB statements (customer and employee requirements) that are not explicitly unveiled by the problem representation. In other studies, conceptual models turned out to be more advantageous than other instruments for this task type ("inference") (cf. (Dunn and Gerard 2001)). As a further finding, we see that participants in group A performed better with regard to task effectiveness although the results of the regression analysis are not statistically significant. This can be a hint that users' "problem-solving skills", which were proposed as an additional factor to influence the "problem solution" (cf. (Vessey and Galletta 1991)) could be an issue at that point. Hence, although the students represent a homogeneous group attending the identical course, students assigned to group A may have been be more skilled in problem-solving than those in group B. In this line, users' ratings of their general software skills and knowledge (see SUMI questionnaire) were slightly better in group A than B, however the effect is statistically not significant. Though, as a limitation, the individual BPI problem-solving abilities of the participants were not investigated. Hence, this aspect is to be examined more closely in upcoming studies.

Efficiency: Second, in terms of efficiency, we see a significant positive relationship between tool I and temporal efficiency, although this effect is only small. More precisely, the temporal efficiency of students using tool II was lower by 0.21

Results for the Excel solution (tool I)	Results for the modeling tool (tool II)





	Mean	***St Dev***	***Median***		***Mean***	***St Dev***	***Median***
Global	43.56	13.55	42.5	**Global**	53.78	11.75	56.5
Efficiency	38.47	14.58	36.0	**Efficiency**	51.56	13.01	53.0
Affect	32.22	15.62	29.0	**Affect**	49.78	15.18	52.5
Helpfulness	47.84	11.22	49.0	**Helpfulness**	55.12	9.69	55.0
Control	43.03	12.23	41.0	**Control**	52.12	9.28	53.5
Learnability	49.47	12.44	51.0	**Learnability**	52.50	11.89	53.0

Dimensions of the SUMI questionnaire (cf. http://sumi.uxp.ie/about/sumipapp.html):
Efficiency: The degree as to which the software supports the user in conducting tasks purposefully and promptly.
Affect: The user's emotional attitude towards the software.
Helpfulness: The degree as to which the software is self-explanatory.
Control: The circumstance whether users are able to handle the software or not.
Learnability: The efforts required for learning to handle the software.

Table 4: Aggregated Results of the SUMI Questionnaires (graphics provided by the HFRG)

percentage points per minute. This aligns with other studies that found drawbacks of conceptual models – compared to other representations – in regards to efficiency (e. g., (Curtis et al. 1989; Green and Petre 1992)). However, different studies come to dissimilar conclusions on this issue (Ritchi et al. 2020).

To find potential explanations for our observation, each BPI technique used for working on the case studies was looked at more closely. It became evident that no differences were observable for tools I and II in case a BPI technique was applied that had a clearly specified form for structuring knowledge, e. g., the SIPOC Diagram or the Ishikawa Diagram. In such cases, the way of secondary level knowledge codification was similar for both tools, because the arrangement and structuring of information was predetermined by the underlying BPI techniques, regardless of conceptual models or spreadsheet templates being used. Considering the SIPOC Diagram for instance (task 1 in experiment 1), suppliers, input, process steps, output and customers are organized in columns with the arrangement of the information being determined by the diagram type itself (cf. (Meran et al. 2013)). In cases where such pre-defined structures were not given for a BPI technique, processing times were longer when working with tool II (and conceptual models). For example, in terms of the CTQ-/CTB-Matrix, the customer and employee requirements needed to be condensed to core statements for being able to specify CTQ and CTB factors. While the corresponding spreadsheet template of tool I directly indicated cells to document this type of information, tool II offered modeling constructs instead and the user was supposed to create a conceptual model. This opens an interesting venue for further research, because either the creation of a mental representation for the CTQ-/CTB-Matrix required additional cognitive efforts, leading to longer processing times, or the documentation of the emerging knowledge by help of tool II. This is to be investigated more closely in upcoming steps.

Moreover, we found a strong and this time also significant impact of the groups (A and B) on efficiency respectively temporal efficiency. Therefore, group A was far more efficient than group B, again indicating better "problem-solving skills" among the participants in group A. Similar observations were already made in regards to effectiveness.

User satisfaction: Third, considering the SUMI results, the modeling-based tool (tool II) was seen as superior to the spreadsheet-based solution (tool I) in regards to user satisfaction from the viewpoint of participants (see Sect. 5.1). Accordingly, participants felt well-supported by tool II when working on the BPI-related problem-solving tasks (e. g., visualization of process, definition of KPIs, etc.) (see Fig. 4 – dimension "efficiency"). Taking a look at the feedback collected via the SUMI questionnaire (item #52), users found tool II particularly helpful for deriving quality specifications – as CTQ and CTB factors – from customer and employee expectations via the help of a conceptual model type for the CTQ-/CTB-Matrix. Since, as previously mentioned, this task builds on the cognitive process "inference" in particular (Larkin and Simon 1987), we receive hints that conceptual models are perceived as helpful to identify relationships between concepts (e. g., VOC and VOB statements) that are not initially exposed by the problem representation.

These findings are backed by the results received for the SUMI item consensual analysis (Kirakowski 1998), because users highly appreciated the functionality of tool II to easily move from one task to another. In contrast, considering the results of the SUMI dimension "efficiency" for tool I, the application of spreadsheet templates was poorly rated by the participants. This subjective perception does not fully harmonize with the results from measuring temporal efficiency, because tool I was rated as superior to tool II in experiment 2 (see Tab. 2). This is an important indication that the form of codifying knowledge – as offered by a tool – affects users' "perceived" support during problem-solving and the conversion of ideas into codified problem solutions. Taking into account the ratings for the SUMI dimension "affect" (see Tab. 4), which was significantly better for tool II, the phenomenon encountered in software usability research that highly aesthetic software is often judged to be usable and helpful (cf. (Ben-Bassat et al. 2006; Norman 2004; Sonderegger and Sauer 2010)) can be observed in our study as well. Moreover, the assessment of "affect" seemed to be independent of the degree as to which a tool was self-explanatory or of the efforts required for learning to handle it (see Tab. 4).

Based on that, we summarize the following insights in regard to the cognitive fit theory in the course of tool-supported BPI projects (see RQ 2).

First, the study provides hints that the effectiveness of the "problem solution" (see Fig. 3) can profit from conceptual model-based software tools that are used for problem-solving in BPI projects. However, a superiority of conceptual model-based to spreadsheet-based tools could not be observed for working on tasks requiring the cognitive process "inference". Hence, the creation of a "mental representation" (see Fig. 3) in BPI does not seem to principally profit from the application of conceptual modeling-based tools to codify results.

Second, considering the efficiency of the "problem solution", we found evidence that spreadsheet templates support the establishment of "mental representations" (to a problem) in case the underlying BPI techniques build on widely established structures for secondary level codification and hence, well-recognized guidelines to arrange information (e. g., diagram types like the Ishikawa Diagram or SIPOC Diagram – see Sect. 2.2). However, corresponding guidelines on how to structure and present emerging knowledge are missing for a large share of BPI techniques, e. g., "bureaucracy elimination" or "brainwriting/Crawford Slip Method" (cf. (Andersen 1999)), which complicates the development of mental representations.

Third, a potential impact of "problem-solving skills" on the "problem solution" (cf. (Vessey and Galletta 1991)) got particularly evident for efficiency. Although, results were slightly better for group A in terms of effectiveness as well, this observation was not statistically significant in light of the regression analysis. Therefore, if "problem-solving skills" of BPI project team members are to be purposefully trained and developed to positively shape the "problem solution", this would call for mapping "task types" (cf. (Larkin and Simon 1987)) with those mechanisms that BPI techniques use to process information (e. g., compare, organize, classify, etc.) (cf. (Hagemeyer et al. 2006)). On that base, a limited set of BPI techniques, which covers each task type could be selected, arranged in form of a roadmap and the employees trained accordingly. That way, problem-solving skills in BPI – considering the prevalent task types and corresponding BPI techniques to cope with them – could be set up within the workforce in a sustainable manner. For instance, techniques with the processing mechanism "organize" (e. g., FMEA) are helpful to arrange the information (Hagemeyer et al. 2006) of the problem representation (Vessey 1991) and derive inferences that finally get evident in the codified results. Hence, such techniques support the cognitive process "recognition" (Larkin and Simon 1987) and are helpful means to address corresponding problem-solving tasks. Similarly, mappings between further task types (e. g., "search, "inference, etc.) (cf. (Larkin and Simon 1987; Ritchi et al. 2020)) and BPI techniques are to be done to define sets of BPI techniques for all common cognitive task types. Accordingly, these insights are valuable for the development of tool support for BPI, which will be outlined in Sect. 6.

5.3 Validity

Regarding the validity of the results, four aspects are to be distinguished (Wohlin et al. 2012). In terms of construct validity (scrutinizing the suitability of the measures for the study), the operational measures used for determining effectiveness and efficiency of problem-solving as well as user satisfaction with a software in this study are commonly accepted and widely spread in research and practice alike.

Considering the internal validity, the influence of third factors (e. g., collaboration between participants) was eliminated as far as possible. Two researchers supervised the experiment to prevent collaboration to the highest possible degree. Further, each participant worked with both tools in the end (cf. (Wohlin et al. 2012)). Thereby, the tools are based on common requirements, the material was handed out on paper and the students worked in a computer lab to assure equal hardware conditions. However, learning effects as regards the BPI discipline cannot be fully excluded due to the time interval between experiment 1 and 2. Though, the students represented a homogeneous group and attended the identical course "quality management". However, as a limitation, students' problem-solving skills were not explicitly investigated. Thereby, in light of the results received, differences between the groups A and B can be assumed. Furthermore, since the students were attending an MIS study program, a general affinity towards conceptual modeling may have existed. However, the course material for "quality management" did not emphasize conceptual modeling in an excessive manner but rather demonstrated the application of BPI techniques for problem-solving. If such a preference for conceptual modeling existed, it could explain some of the SUMI results but not the findings for effectiveness or efficiency. Nevertheless, the questionnaire did not analyze users' preferences in this regard.

External validity deals with the generalizability of the results (Wohlin et al. 2012). A laboratory setting was chosen deliberately to analyze the effect of software-based codification approaches on effectiveness, efficiency and user satisfaction. However, our tools may not be representative for all commercial or open source software and spreadsheet templates for BPI thus limiting the generalizability of the results, and further research is necessary. We consider our study as a first step in a larger empirical evaluation for which the use of students has been found to be adequate (Parsons and Cole 2005).

In terms of reliability, the operational measures were standardized and widely acknowledged, making the results independent of particular researchers. Finally, the number of participants exceeded the required sample size as mentioned by the HFRG for coming to meaningful insights (http://sumi.uxp.ie/about/sumipapp.html).

6 Benefits

Our research deals with the codification of knowledge in BPI projects by help of spreadsheet-based and conceptual modeling-based software tools. Thereby, our research is beneficial for research and practice alike.

6.1 Benefits for Research

At first, the codification of emerging knowledge in BPI projects, and particularly, the question of how to present the information (secondary level of codification) is still a largely under-researched topic in literature. In this respect, many existing BPI approaches that refer to user's implicit process knowledge (see Sect. 2.1) are perceived as over-dimensioned by practitioners (cf. (Davis 2013; Hawkins 2019; Pande et al. 2014)), who prefer a limited set of BPI techniques instead, as provided by our BPI roadmap for instance. Our study addresses this gap and analyses how software, realized as a conceptual model-based or spreadsheet-based solution, impacts the effectiveness and efficiency of problem-solving in BPI. Moreover, the effect of the design on user satisfaction is examined (see RQ 1).

Hence, we got hints that the effectiveness and efficiency of problem-solving do not necessarily depend on whether a conceptual modeling-based or spreadsheet-based tool is used. Much more, the cognitive processes involved in problem-solving (Larkin and Simon 1987) and the existence of widely-recognized guidelines to codify information have to be considered in terms of BPI techniques (e. g., diagram types, etc.). For instance, the advantages of conceptual models for certain cognitive task types (e. g., "inference") that have been unveiled for particular domains (e. g., accounting) (cf. (Dunn and Gerard 2001)) could not be observed in our study for the field of BPI. Rather, the efficiency strongly profited from clear arrangements on how to structure and codify results as offered by tool I. Therefore, the field of BPI, which subsumes a lot of poorly formalized BPI techniques (see Sect. 2.2) is different to domains for which formal modeling techniques have been defined (e. g., (Bork and Fill 2014)).

This is an important issue for the construction of user-adapted BPI roadmaps (see Sect. 2.1). On the one hand, research should match the underlying processing mechanisms of BPI techniques (Hagemeyer et al. 2006) with the cognitive processes found for problem-solving in BPI more profoundly. On that base, existing BPI technique selection frameworks can be further developed, as techniques' appropriateness to cope with different types of cognitive processes can be validated (e. g., (Hagemeyer et al. 2006; Johannsen et al. 2015; Uluskan 2016)). On the other hand, research should further work on the establishment of guidelines for the codification of information, especially for those techniques, which lack a formal base, e. g., "bureaucracy elimination" (cf., (Andersen 1999)). This would support the construction of roadmaps that address the various cognitive problem-solving processes and offer defined guidelines for knowledge codification at each stage of a BPI project (e. g., (Pande et al. 2014; Povey 1998)). At that point, our study also uncovered a beneficial role of conceptual models in terms of "user satisfaction". Thus, conceptual models support the communication between users as complex issues in BPI can be visualized in a comprehensible manner (e. g., KPIs and their relation to project goals). As mentioned in Sect. 2.1, some BPI approaches can be found, which explicitly use conceptual models to demonstrate results (e. g., (Ferrante et al. 2016)). So far, we developed conceptual model types for the BPI techniques of the BPI roadmap and further model types will be designed in future research.

Second, regarding the cognitive fit theory (see RQ 2), users tend to formulate a mental representation of the problem, which is consistent with the type of information in the first problem-solving element considered (Vessey and Galletta 1991). Generally, the conceptual model-based tool (tool II) emphasizes "perceptual" problem-solving processes (as relations between results are explicitly visualized) whereas the spreadsheet-based tool (tool I) is supposed to be more suitable for "analytical" processes (cf. (Vessey and Galletta 1991)). However, it was shown that no significant impact on the task effectiveness of problem-solving was given in our experiments. Tool I performed slightly better in terms of efficiency, which opposes our initial assumption. Furthermore, a task-related analysis of the data gave hints that the BPI techniques applied as well as the cognitive task types required for problem-solving have to be carefully considered when choosing tool-support (see Sect. 5.2). Accordingly, BPI research should work on identifying typical problem-solving tasks as well as problem representation forms that are encountered in BPI projects and match these with cognitive processes for solution development. If these constellations are better understood by research, suggestions on how to select BPI techniques more purposefully to increase task effectiveness and efficiency can be developed along with corresponding knowledge codification forms. Though, it could be shown that tool-based BPI codification approaches for problem-solving in BPI projects affect the "perceived" efficiency and users' satisfaction with a tool.

Furthermore, the "problem-solving skill", which describes particular procedures a person uses to solve a problem (Vessey and Galletta 1991), an element enhancing the basic cognitive fit model, might be a major influencing factor on the effectiveness and efficiency of problem-solving in BPI. For our experiment, we considered a homogeneous group of students in order to assume an equal level of "problem-solving skills". However, considering the results, group A seemed to have superior skills compared to group B. Considering this, the role of the element "problem-solving skills" in regard to problem-solving in BPI projects needs to be investigated in further studies more closely. This will include participants with different knowledge in the BPI field to identify the types of expertise affecting "problem-solving skills" the best possible way.

6.2 Benefits for Practice

First, benefits for practice arose as two tools were generated for supporting employees during BPI projects, helping to substitute the documentation of knowledge via tables, lists or sketches. Thereby, the tools build on a proven BPI roadmap that was successfully applied in several BPI projects in practice. Hence, workforce is not only provided with an easy-to-use approach on how to conduct BPI projects but also corresponding software tools. Therefore, employees do not have to become acquainted with different BPI approaches (e. g., Six Sigma, Lean Management, etc.) but may focus on the limited set of proposed BPI techniques exclusively. This is particularly relevant because workforce usually neither has the time nor the motivation to get familiar with more than one approach (cf. (Gijo and Rao 2005)).

Second, beneficial insights into the development of software products for BPI emerged. From a general perspective, conceptual models seem to contribute to users' perceived satisfaction, whereas spreadsheet templates turned out to be quick in terms of documenting results in our experiment. Tool developers may combine both forms of codification in their software products. Accordingly, in case BPI techniques are used, which have a well-recognized form to structure and codify results, spreadsheet templates may be designed for the user interface to increase users' task efficiency. Examples for such techniques comprise the "FMEA", "Quality Function Deployment (QFD)" or the "Measurement Matrix" just to mention a few (e. g., (Akao 1990; Meran et al. 2013)). At that point, we acknowledge that a familiarity with MS Excel does not automatically lead to a positive user attitude towards spreadsheet templates for BPI. In our experiment, participants' familiarity with MS Excel was given due to a previous course "fundamentals of IT" that had to be accomplished by all students. However, the SUMI results for tool I in terms of "affinity" were far beyond those of tool II. This finding is relevant, as a lot of companies use corresponding templates for BPI projects, which were created by help of traditional office software products. For less formalized BPI techniques (e. g., "bureaucracy elimination"), conceptual models may help users to decrease complexity of the problem situation and visualize interrelations between solution modules.

Third, considering the role of problem-solving skills in BPI, it is suggested to use a selected set of BPI techniques for projects only and provide corresponding training programs for these techniques in special (cf. (Antony and Gupta 2019)). By that, technique-related competencies are established within the workforce. Besides, since many BPI techniques are driven by the process knowledge of participants (cf. (Hagemeyer et al. 2006; Seethamraju and Marjanovic 2009)) domain knowledge is a further success factor in BPI (Antony and Gupta 2019). Accordingly, those employees who are directly involved in the execution of a process should be part of the project team (e. g., (Goodman and Theuerkauf 2005)). In the future, research will work on the identification of types of expertise affecting "problem-solving skills" in more depth, and hence, additional suggestions can be posed.

7 Conclusion and Outlook

Our study compares two tool-based BPI codification approaches in terms of efficiency, effectiveness and user satisfaction. In this context, the benefits of conceptual modeling regarding user satisfaction clearly became evident. The insights were reflected against the theory of cognitive fit.

As a limitation, the study was conducted with students, not practitioners. Although the assignment of students to groups was random, group A seemed to have more profound problem-solving skills, which is reflected by the results as described. Additional studies with practitioners will have to be done in the future to better analyze the influence of the "problem-solving skills" on problem-solving performance in BPI. Currently, the study was performed with 32 students only. Nevertheless, this sample size is sufficient for getting meaningful results with the SUMI approach as stated by the HFRG. Therefore, the necessity of acquiring a relatively small number of participants only is a major benefit of SUMI. Though, a more comprising sample set is strived for in further research. In this respect, also a more granular analysis of the application of particular BPI techniques for certain tasks will be done. In the study at hand, the effectiveness was analyzed considering the case studies as a whole and an analysis of conceptual model-based or spreadsheet-based codification approaches for singular tasks (e. g., establishment of a SIPOC Diagram) is strived for. Additionally, BPI projects are often conducted in collaboration and, hence, we will investigate the problem-solving abilities of "groups" more profoundly.

In the future, the results will be used for the design and implementation of tools to support BPI initiatives. Therefore, the forms of codifying knowledge will be defined on base of the BPI techniques applied and cognitive processes required for problem-solving. In this line, a graphical user interface is to be created that helps users to select BPI techniques depending on the problem to be solved. Furthermore, we plan to conduct a larger empirical evaluation of the tools with practitioners. At that point, eye trackers may be applied to assess cognitive processes and hence the creation of mental representations more purposefully (cf. (Asan and Yang 2015)).

References

Adesola S., Baines T. (2005) Developing and evaluating a methodology for business process improvement. In: Business Process Management Journal 11(1), pp. 37–46

Akao Y. (1990) QFD: Integrating Customer Requirements into Product Design. Productivity Press

Alexander C., Ishikawa S., Silverstein M., Jacobson M., Fiksdahl-King I., Angel S. (1977) A pattern language. Towns, Buildings, Construction. Oxford University Press

Amaravadi C. S., Lee I. (2005) The dimensions of process knowledge. In: Knowledge and Process Management 12(1), pp. 65–76

Anaby-Tavor A., Amid D., Fisher A., Bercovici A., Ossher H., Callery M., Desmond M., Krasikov S., Simmonds I. (2010) Insights into enterprise conceptual modeling. In: Data & Knowledge Engineering 69(12), pp. 1302–1318

Andersen B. (1999) Business process improvement toolbox. ASQ Quality Press

Antony J., Gupta S. (2019) Top ten reasons for process improvement project failures. In: International Journal of Lean Six Sigma 10(1), pp. 367–374

Asan O., Yang Y. (2015) Using eye trackers for usability evaluation of health information technology: a systematic literature review. In: JMIR human factors 2(1), e4062

Baskerville R., Baiyere A., Gregor S., Hevner A., Rossi M. (2018) Design science research contributions: finding a balance between artifact and theory. In: Journal of the Association for Information Systems 19(5), pp. 358–376

Becker J., Bergener P., Räckers M., Weiß B., Winkelmann A. (2010) Pattern-based semi-automatic analysis of weaknesses in semantic business process models in the banking sector. In: European Conference on Information Systems (ECIS) 2010

Becker J., Delfmann P., Dietrich H.-A., Steinhorst M., Eggert M. (2016) Business process compliance checking – applying and evaluating a generic pattern matching approach for conceptual models in the financial sector. In: Information Systems Frontiers 18(2), pp. 359–405

Beerepoot I., Weerd I. v. d., Reijers H. A. (2019) Business process improvement activities: differences in organizational size, culture, and resources. In: International Conference on Business Process Management. Lecture Notes in Computer Science Vol. 11675. Springer, pp. 402–418

Ben-Bassat T., Meyer J., Tractinsky N. (2006) Economic and subjective measures of the perceived value of aesthetics and usability. In: ACM Transactions on Computer-Human Interaction (TOCHI) 13(2), pp. 210–234

Bergener P., Delfmann P., Weiss B., Winkelmann A. (2015) Detecting potential weaknesses in business processes: An exploration of semantic pattern matching in process models. In: Business Process Management Journal 21(1), pp. 25–54

Bevan N. (1995) Measuring usability as quality of use. In: Software Quality Journal 4(2), pp. 115–130

Bjerke M. B., Renger R. (2017) Being smart about writing SMART objectives. In: Evaluation and program planning 61, pp. 125–127

Bork D., Fill H.-G. (2014) Formal Aspects of Enterprise Modeling Methods: A Comparison Framework. In: System Sciences (HICSS), 2014 47th Hawaii International Conference on. IEEE, pp. 3400–3409

Breyfogle F. W. (2010) Process improvement projects shortcomings and resolution. In: International Journal of Lean Six Sigma 1(2), pp. 92–98

Burton-Jones A., Meso P. (2006) Conceptualizing Systems for Understanding: An Empirical Test of Decomposition Principles in Object-Oriented Analysis. In: Information Systems Research 17(1), pp. 38–60

Clark T., Sammut P., Willans J. (2008) Applied metamodelling: a foundation for language driven development. In:

Coskun S., Basligil H., Baracli H. (2008) A weakness determination and analysis model for business process improvement. In: Business Process Management Journal 14(2), pp. 243–261

Curtis B., Sheppard S. B., Kruesi-Bailey E., Bailey J., Boehm-Davis D. A. (1989) Experimental evaluation of software documentation formats. In: Journal of systems and software 9(2), pp. 167–207

Dalkir K. (2005) Knowledge management in theory and practice. McGill University

Davis D. (2013) 3rd Biennial PEX Network Report: State of the Industry - Trends and Success Factors in Business Process Excellence. Report

Diefenbach S., Kolb N., Hassenzahl M. (2014) The'hedonic'in human-computer interaction: history, contributions, and future research directions. In: Proceedings of the 2014 conference on Designing interactive systems, pp. 305–314

Dumas M., La Rosa M., Mendling J., Reijers H. A. (2013) Fundamentals of Business Process Management. Springer

Dunn C. L., Gerard G. J. (2001) Auditor efficiency and effectiveness with diagrammatic and linguistic conceptual model representations. In: International Journal of Accounting Information Systems 2(4), pp. 223–248

Falk T., Griesberger P., Leist S. (2015) Patterns as an artifact for business process improvement-insights from a case study. In: Design Science at the Intersection of Physical and Virtual Design. Lecture Notes in Computer Science Vol. 7939. Springer, pp. 88–104

Fellmann M., Koschmider A., Laue R., Schoknecht A., Vetter A. (2019) Business Process Model Patterns-Classification and Repository of Published Work. In: EMISA Forum Vol. 39. De Gruyter, pp. 67–75

Ferrante S., Bonacina S., Pozzi G., Pinciroli F., Marceglia S. (2016) A design methodology for medical processes. In: Applied clinical informatics 7(1), pp. 191–210

Fill H.-G., Karagiannis D. (2013) On the Conceptualisation of Modelling Methods Using the ADOxx Meta Modelling Platform. In: Enterprise Modelling and Information Systems Architectures-An International Journal 8(1), pp. 4–25

Fill H., Johannsen F. (2016) A Knowledge Perspective on Big Data by Joining Enterprise Modeling and Data Analyses. In: 49th Hawaii International Conference on System Sciences, HICSS 2016, Koloa, HI, USA, January 5–8, 2016. IEEE, pp. 4052–4061

Forster F. (2006) The Idea behind Business Process Improvement: Toward a Business Process Improvement Pattern Framework. In: BPTrends, pp. 1–13

Gemino A., Wand Y. (2004) A framework for empirical evaluation of conceptual modeling techniques. In: Requirements Engineering 9(4), pp. 248–260

George M. L., Rowlands D., Price M., Maxey J. (2005) Lean Six Sigma Pocket Toolbox. McGraw-Hill

Gijo E. V., Rao Tummala S. (2005) Six Sigma Implementation – Hurdles and More Hurdles. In: Total Quality Management & Business Excellence 16(6), pp. 721–725

Goldkuhl G., Karlsson F. (2020) Method engineering as design science. In: Journal of the Association for Information Systems 21(5), pp. 1237–1278

Goodman J., Theuerkauf J. (2005) What's Wrong With Six Sigma? In: Quality Progress, pp. 37–42

Grant D. (2016) Business analysis techniques in business reengineering. In: Business Process Management Journal 22(1), pp. 75–88

Green T. R., Petre M. (1992) When visual programs are harder to read than textual programs. In: Human-Computer Interaction: Tasks and Organisation, Proceedings of ECCE-6 (6th European Conference on Cognitive Ergonomics). GC van der Veer, MJ Tauber, S. Bagnarola and M. Antavolits. Rome, CUD. Citeseer, pp. 167–180

Griesberger P., Leist S., Zellner G. (2011) Analysis of Techniques for Business Process Improvement. In: 19th European Conference on Information Systems (ECIS 2011), pp. 239–250

Hagemeyer C., Gershenson J. K., Johnson D. M. (2006) Classification and application of problem solving quality tools: A manufacturing case study. In: The TQM Magazine 18(5), pp. 455–483

Hall M. (2006) Knowledge management and the limits of knowledge codification. In: Journal of Knowledge Management 10(3), pp. 117–126

Harmon P. (2018) The State of Business Process Management - 2018. Report. https://www.bptrends.com/bpt/wp-content/uploads/2018--BPM-Survey.pdf

Harmon P., Garcia J. (2020) The State of Business Process Management - 2020. Report. https://www.bptrends.com/bptrends-state-of-business-process-management-2020--report/

Harmon P., Wolf C. (2011) Business Process Modeling Survey. In: Business Process Trends (http://www. bptrends. com/)

Harrington H., Lomax K. (2000) Performance Improvement Methods: Fighting the War on Waste. McGraw-Hill

Harrington H., Esseling E., Van Nimwegen H. (1997) Business Process Improvement – Documentation, Analysis, Design and Management of Business Process Improvement. McGraw-Hill

Harrington J. (1991) Business Process Improvement – The Breakthrough Strategy for Total Quality, Productivity and Competiveness. McGraw-Hill

Hawkins I. (2018) THE PEX REPORT 2018. Report. https://www.processexcellencenetwork.com/innovation/articles/pex-network-annual-report

Hawkins I. (2019) THE PEX REPORT 2020. Report. https://www.processexcellencenetwork.com/innovation/articles/pex-network-annual-report

Hayes A. F., Krippendorff K. (2007) Answering the call for a standard reliability measure for coding data. In: Communication methods and measures 1(1), pp. 77–89

Hevner A. R. (2007) A three cycle view of design science research. In: Scandinavian journal of information systems 19(2), pp. 87–92

Hevner A. R., March S. T., Park J., Ram S. (2004) Design Science in Information Systems Research. In: MIS Quarterly 28(1), pp. 75–105

Hofmann M. (2020) Prozessoptimierung als ganzheitlicher Ansatz. Springer

Ishikawa K. (1980) Guide to Quality Control

Johannsen F. (2017) Functional Interdependencies between Quality Techniques reverting to Meta Models. In: Wirtschaftsinformatik

Johannsen F., Fill H. (2014) Codification of Knowledge in Business Process Improvement Projects. In: 22st European Conference on Information Systems, ECIS 2014, Tel Aviv, Israel, June 9–11, 2014

Johannsen F., Fill H. (2017) Meta Modeling for Business Process Improvement. In: Bus. Inf. Syst. Eng. 59(4), pp. 251–275

Johannsen F., Leist S., Zellner G. (2011) Six sigma as a business process management method in services: analysis of the key application problems. In: Information Systems and E-Business Management 9(3), pp. 307–332

Johannsen F., Leist S., Zellner G. (2015) Implementing Six Sigma for Improving Business Processes at an Automotive Bank In: Handbook on Business Process Management 1, 2nd edition Springer, pp. 361–382

Kettinger W. J., Teng J. T., Guha S. (1997) Business Process Change: A study of methodologies, techniques, and tools. In: MIS Quarterly 21(1), pp. 55–80

Khatri V., Vessey I., Ramesh V., Clay P., Park S.-J. (2006) Understanding Conceptual Schemas: Exploring the Role of Application and IS Domain Knowledge. In: Information Systems Research 17(1), pp. 81–99

Kirakowski J. (1998) SUMI user handbook. In: Human Factors Research Group, University College Cork, Ireland

Kirakowski J., Corbett M. (1993) SUMI: The software usability measurement inventory. In: British journal of educational technology 24(3), pp. 210–212

Klochkov Y., Tveryakov A. (2020) Approaches to the improvement of quality management methods. In: International Journal of System Assurance Engineering and Management 11, pp. 163–172

Koschmider A., Laue R., Fellmann M. (2019) Business process model anti-patterns: a bibliography and taxonomy of published work. In: European Conference on Information Systems (ECIS) 2019

Lacy D. (2001) A theory of nonseparable preferences in survey responses. In: American Journal of Political Science 45(2), pp. 239–258

Lang M., Wehner B., Falk T., Griesberger P., Leist S. (nodate) Evaluating Business Process Improvement Patterns by Simulation. In: 23rd European Conference on Information Systems (ECIS 2015)

Larkin J. H., Simon H. A. (1987) Why a diagram is (sometimes) worth ten thousand words. In: Cognitive science 11(1), pp. 65–100

Laudon K. C., Laudon J. P. (2014) Essentials of MIS. Pearson Education Limited

Lewis J. R. (2018) Measuring perceived usability: The CSUQ, SUS, and UMUX. In: International Journal of Human–Computer Interaction 34(12), pp. 1148–1156

Lindland O. I., Sindre G., Sølvberg A. (1994) Understanding Quality in Conceptual Modeling. In: IEEE Software 11(2), pp. 42–49

Lohrmann M., Reichert M. (2016) Effective application of process improvement patterns to business processes. In: Software & Systems Modeling 15(2), pp. 353–375

Lückmann P., Feldmann C. (2017) Success factors for business process improvement projects in small and medium sized enterprises–empirical evidence. In: Procedia computer science 121, pp. 439–445

Mansor Z., Kasirun Z. M., Yahya S., Arshad N. H. (2012) The Evaluation of WebCost Using Software Usability Measurement Inventory (SUMI). In: International Journal of Digital Information and Wireless Communications (IJDIWC) 2(2), pp. 197–201

March S. T., Smith G. F. (1995) Design and natural science research on information technology. In: Decision support systems 15(4), pp. 251–266

Măruşter L., van Beest N. R. (2009) Redesigning business processes: a methodology based on simulation and process mining techniques. In: Knowledge and Information Systems 21(3), pp. 267–297

McAdam R., Donaghy J. (1999) Business process re-engineering in the public sector: a study of staff perceptions and critical success factors. In: Business Process Management Journal 5(1), pp. 33–49

McGee-Abe J. (2015) 4th Biennial PEX Network Report: Aligning Strategy with Operational Excellence to Drive Sustainable, Enterprise-Wide Transformation. Report. https://www.processexcellencenetwork.com

McGovern T., Small A., Hicks C. (2017) Diffusion of process improvement methods in European SMEs. In: International Journal of Operations & Production Management 37(5), pp. 607–629

Meran R., John A., Roenpage O., Staudter C. (2013) Six Sigma+Lean Toolset. Springer

Mukerjee K. (2013) Customer-oriented organizations: a framework for innovation. In: Journal of Business Strategy 34(3), pp. 49–56

Mylopoulos J. (1992) Conceptual Modeling and Telos In: Conceptual Modelling, Databases and CASE: An Integrated View of Information Systems Development Wiley, pp. 49–68

Noori B., Latifi M. (2018) Development of Six Sigma methodology to improve grinding processes. In: International journal of lean six sigma 9(1), pp. 50–63

Norman D. A. (2004) Emotional design: Why we love (or hate) everyday things. Basic Civitas Books

Palkina E. S. (2018) Using business process improvement concept to optimize enterprise production system in conditions of innovative economic development. In: MATEC Web of Conferences Vol. 224. EDP Sciences, p. 02011

Pande P., Neuman R., Cavanagh R. (2014) The Six Sigma Way: How to maximize the impact of your change and improvement efforts. McGraw Hill Professional

Park S., Kang Y. S. (2016) A study of process mining-based business process innovation. In: Procedia Computer Science 91(Itqm), pp. 734–743

Parsons J., Cole L. (2005) What do the pictures mean? Guidelines for experimental evaluation of representation fidelity in diagrammatical conceptual modeling techniques. In: Data & Knowledge Engineering 55(3), pp. 327–342

Peffers K., Tuunanen T., Rothenberger M. A., Chatterjee S. (2007) A design science research methodology for information systems research. In: Journal of management information systems 24(3), pp. 45–77

Polyvyanyy A., Ouyang C., Barros A., van der Aalst W. M. (2017) Process querying: Enabling business intelligence through query-based process analytics. In: Decision Support Systems 100, pp. 41–56

Pourshahid A., Mussbacher G., Amyot D., Weiss M. (2013) Requirements for a modeling language to specify and match business process improvement patterns. In: 2013 3rd International Workshop on Model-Driven Requirements Engineering (MoDRE). IEEE, pp. 10–19

Povey B. (1998) The development of a best practice business process improvement methodology. In: Benchmarking: An International Journal 5(1), pp. 27–44

Ritchi H., Jans M., Mendling J., Reijers H. A. (2020) The influence of business process representation on performance of different task types. In: Journal of Information Systems 34(1), pp. 167–194

Satyal S., Weber I., Paik H.-y., Di Ciccio C., Mendling J. (2019) Business process improvement with the AB-BPM methodology. In: Information Systems 84, pp. 283–298

Sauro J., Lewis J. R. (2012) Quantifying the user experience: Practical statistics for user research. Elsevier

Seethamraju R., Marjanovic O. (2009) Role of process knowledge in business process improvement methodology: a case study. In: Business Process Management Journal 15(6), pp. 920–936

Shaft T. M., Vessey I. (2006) The role of cognitive fit in the relationship between software comprehension and modification. In: Mis Quarterly 30(1), pp. 29–55

Smolnik S., Urbach N., Fjermestad J. L., Winkelmann A., Weiß B. (2011) Automatic identification of structural process weaknesses in flow chart diagrams. In: Business Process Management Journal 17(5), pp. 787–807

Snee R., Hoerl R. (2003) Leading Six Sigma. Prentice Hall

Sonderegger A., Sauer J. (2010) The influence of design aesthetics in usability testing: Effects on user performance and perceived usability. In: Applied ergonomics 41(3), pp. 403–410

Stoesser K. R. (2019) Entwicklung der Prozessoptimierung In: Prozessoptimierung für produzierende Unternehmen Springer, pp. 5–26

Stojanović D., Slović D., Tomašević I., Simeunović B. (2016) Model for selection of business process improvement methodologies. In: Toulon-Verona Conference" Excellence in Services"

Sutherland J., Schwaber K. (2007) The scrum papers. In: Nuts, Bolts and Origins of an Agile Process

Trkman P. (2010) The critical success factors of business process management. In: International journal of information management 30(2), pp. 125–134

Uluskan M. (2016) A comprehensive insight into the Six Sigma DMAIC toolbox. In: International Journal of Lean Six Sigma 7(4), pp. 406–429

Van Der Aalst W., Adriansyah A., de Medeiros A. K. A., Arcieri F., Baier T., Blickle T., Bose J. C., van den Brand P., Brandtjen R., Buijs J. (2012) Process mining manifesto. In: Business process management workshops. Lecture Notes in Business Information Processing Vol. 99. Springer, pp. 169–194

Vanwersch R. J. B., Shahzad K., Vanderfeesten I., Vanhaecht K., Grefen P., Pintelon L., Mendling J., Merode G. G., Reijers H. A. (2016) A Critical Evaluation and Framework of Business Process Improvement Methods. In: Business & Information Systems Engineering 58(1), pp. 43–53

Vashnavi V., Kuechler W. (Oct. 2004) Design Research in Information Systems. Report. http://desrist.org/design-research-in-information-systems/

van Veenendaal E. (1998) Questionnaire based usability testing. In: European Software Quality Week Vol. 1

Vessey I. (1991) Cognitive fit: A theory-based analysis of the graphs versus tables literature. In: Decision Sciences 22(2), pp. 219–240

Vessey I., Galletta D. (1991) Cognitive fit: An empirical study of information acquisition. In: Information systems research 2(1), pp. 63–84

Vessey I., Zhang P., Galletta D. (2006) The theory of cognitive fit. In: Human-computer interaction and management information systems: Foundations, pp. 141–183

Villanueva M. S. (2021) How Microsoft 365 can improve your process documentation? Report. https://www.itsasap.com/blog/office-365--process-documentation

Wand Y., Weber R. (2002) Research Commentary: Information Systems and Conceptual Modeling - A Research Agenda. In: Information Systems Research 13(4), pp. 363–376

Wang H.-M. S., Wang S.-P., Lee W. (2014) A Case Study for Reducing Client Waiting Time in a Health Evaluation Center Using Design for Six Sigma. In: Engineering Management Journal 26(2), pp. 62–73

Weber I., Mendling J. (2015) A Vision of Experimental Process Improvement. In: SIMPDA 15, pp. 127–130

Wohlin C., Runeson P., Höst M., Ohlsson M. C., Regnell B., Wesslén A. (2012) Experimentation in Software Engineering. Springer

Zellner G. (2011) A Structured Evaluation of Business Process Improvement Approaches. In: Business Process Management Journal 17(2), pp. 203–237

Zellner G. (2013) Towards a framework for identifying business process redesign patterns. In: Business Process Management Journal 19(4), pp. 600–623

Zhang J., Norman D. A. (1994) Representations in distributed cognitive tasks. In: Cognitive science 18(1), pp. 87–122