1 | New Perspectives on Logistics and Supply Chain Management

Rethinking Business Process Maturity Models

Reflection on a Research Cycle to Further Advance the Domain

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UNIVERSITY OF BAMBERG
CHAIR OF OPERATIONS MANAGEMENT & LOGISTICS

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The successful management of internal and cross-company value-added processes, value chains, and entire networks depends in particular on the purposeful application of existing and advanced methods and concepts of production and logistics management and operations research, the use of innovative information and communication technologies, and theoretical and practical findings in process management. The series aims to publish new research results in the areas of production and logistics management, supply chain management, and e-commerce. Publications that contribute to scientific progress in these areas are selected.

Rethinking Business Process Maturity Models – Reflection on a Research Cycle to Further Advance the Domain

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The thesis at hand has been submitted to the Faculty of Social Sciences, Economics, and Business Administration of the University of Bamberg as a dissertation.

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Preface

Maturity models are a well-known tool in business practice. Management consultancies, in particular, promote such models as part of their services. Examples include the Boston Consulting Group's Digital Acceleration Index, Roland Berger's Robustness Maturity Index, KPMG's Logistics Maturity Analysis, and McKinsey's Digital Quotient. Maturity models have their roots in software development. The best-known maturity model is the Capability Maturity Model (CMM), developed in the late 1980s by the Software Engineering Institute (SEI) at Carnegie Mellon University. Initially, the CMM focused on evaluating and improving software development processes, but could also be applied to other processes, such as project management. In the early 2000s, it was replaced by the Capability Maturity Model Integration (CMMI). The revision's objective was to focus on different areas, such as product development, services, and procurement, and to be able to apply it therein. CMMI, therefore, integrates several maturity models that relate to different aspects of the organization, hence the name "Capability Maturity Model Integration".

Since companies have adopted a process-oriented perspective and process management has turned into a company-wide – as well as cross-company – management task, the continuous revision of operational processes has been considered one of the main tasks of process management. Maturity models can support the targeted refinement of processes by providing a useful tool for determining the current status and identifying potential for improvement. A maturity model consists of a sequence of so-called maturity levels and thus describes an expected, desired, or typical development path. Regardless of the maturity model used, the goal in business practice is usually to increase the maturity level in line with the goal of process refinement. In the automotive industry, for example, it is common for customers to expect a defined minimum maturity level of the processes of future suppliers and their continuous development in their tenders – "Maturity Level Assurance for New Parts in the Automotive Industry" (RGA) of the VDA (Verband der Automobilindustrie).

In general, maturity models are designed to support organizations in assessing and revising their processes, practices, and capabilities. This type of maturity model is also known as business process maturity model (BPMM). It provides a structured method for measuring an organization's maturity in various areas. Applying such models, it is ideally possible to (1) identify the current state, (2) derive specific goals, (3) initiate improvements, and (4) conduct comparisons. Overall, maturity models promise to support organizations in enhancing their performance, establishing a culture of continuous improvement, and minimizing risks, which is appealing to decision makers. But does it really make sense to use such models? Does the application of such a model really increase the company's results? Some doubts exist. So far, there is no empirical evidence of such a relation. This motivates Ms. Felch's dissertation, formulating the following main research question: "Which points of criticism are inherent in BPMMs with regard to the design and publication process that limit the models' usefulness and applicability and how can these be overcome?".

Ms. Felch's dissertation is, therefore, primarily at the level of normative research. The development process of her work is impressive. The author initially derives suggestions for business practice and then delves into academic research in remarkable depth. Based on her own experience in developing and applying a BPMM for the delivery process in supply chains (which is the first practice- and application-oriented contribution of this dissertation), she initiates a reflection of the research process (i.e., reflection-on-action). The weaknesses identified within its own model motivate further research, which results in a catalog of requirements for improving the quality of newly developed or revised BPMMs. Methodologically, the work is based on the analysis and comparison of existing literature.

Ms. Felch addresses the practically relevant and theoretically meaningful problem of developing, applying, and validating maturity models. Overall, this dissertation impressively reflects Ms. Felch's outstanding professional and methodological expertise. The author succeeds in scientifically locating her dissertation topic in all its facets and then presenting a framework with guidelines that can be used by decision makers to further increase the quality of maturity models, their applicability in practice, and thus their dissemination. Overall, Ms. Felch's work provides a considerable and lasting contribution to scientific progress. It is also highly relevant to business practice.

Univ.-Prof. Dr. Eric Sucky

Acknowledgments

"You do not just wake up and become the butterfly – growth is a process."
Rupi Kaur, The Sun and Her Flowers, 2017, p. 87

The dissertation is the result of a long-term process that reflects personal and professional development. Part of this is structuring knowledge and acquiring new skills and capabilities. It is a phase of continuous learning and self-reflection that involves struggling with setbacks, overcoming challenges, and celebrating successes. Piece by piece, the fragments form a coherent picture. The journey concludes with a finished work in hands showing the result of this growth process that would not have been possible without the support of the people around me.

First and foremost, I would like to sincerely thank my supervisor Prof. Dr. Eric Sucky, who has always supported me over the years. I am particularly grateful for three aspects. First, he trained me not to lose sight of the big picture, no matter in which phase of the dissertation, and persistently pursue my objective. Second, he provided me with the necessary freedom to develop my research and follow my own path. Third, he shared valuable advice and feedback that will also serve as a guide in my future career. My special thanks likewise belong to Prof. Dr. Martin Friesl, Prof. Dr. Silvia Annen, and Prof. Dr. Amy van Looy, who not only completed my doctoral committee, but also contributed to the finalization of my dissertation by providing valuable advice.

Furthermore, I thank my current and former colleagues at the Chair of Operations Management & Logistics for their support in the various phases of the past years. Besides collegial cooperation and countless constructive discussions, they have also made the time aside from the dissertation unforgettable. Beyond that, I would like to thank my co-author, Dr. Björn Asdecker, for the rewarding teamwork that allowed me to complete this journey successfully. Feedback and novel perspectives on my research have been of great value throughout the process. Moreover, I am grateful to receive support from several peers outside the department. The exchange and their insights have helped me to further develop my research.

Last but not least, I would like to express my gratitude to my family and friends, who have accompanied me along the way. They have always encouraged me to pursue my goals and have contributed to my perseverance and success.

All together, they have had a lasting impact on my development. Thank you very much!

Abstract

Various developments, such as economic uncertainties, growing market dynamics, or unexpected events, e.g., the COVID-19 pandemic, affect organizations and their business processes. To remain competitive and ensure long term survival, organizational capabilities and processes need to be continuously adapted. Numerous (business process) maturity models have been released as guidance for organizations, which can assist in determining the current state, highlighting improvement measures, and enabling cross-organizational comparisons.

Although the ascribed potential seems high, this dissertation takes a critical perspective by (1) highlighting prevailing points of criticism of models that are inherent in the design and publication process, (2) verifying the anecdotal evidence of these issues, (3) identifying reasons for the points of criticism, and (4) suggesting the framework REMMAP to enhance upcoming model designs and improve released maturity models.

The dissertation contributes to the existing body of knowledge by (1) drawing the attention of model designers to prevailing points of criticism to improve the design and publication of released and future models, (2) assisting reviewers and editors in thoroughly screening submitted works, and (3) supporting users in selecting appropriate models as well as providing them with more substantiated and transparent models in the future.

Keywords. Business Process Maturity Model · Maturity Model · Reflection · Points of Criticism · Model Design · Framework

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List of Abbreviations

B09	Article by Becker et al. (2009)
BPM	Business Process Management
BPM-CF	Business Process Management Capability Framework by Rosemann/de Bruin (2005)
BPM-MC	Business Process Maturity by McCormack (2007)
BPMM-OMG	Business Process Maturity Model by Object Management Group
BPMM(s)	Business Process Maturity Model(s)
BPO-MM	Business Process Orientation Maturity Model by McCormack/Johnson (2001)
BS	Backward Search
CMMI	Capability Maturity Model Integration
CPLS	Cyber-physical Logistics Systems
CPS	Cyber-physical Systems
D05	Article by de Bruin et al. (2005)
DCT	Dynamic Capability Theory
DPMM 4.0	Delivery Process Maturity Model 4.0
DSR	Design Science Research
EXW	Ex Works
FS	Forward Search
ICT	Information and Communication Technology
IoT	Internet of Things
IS	Information Systems
M10	Article by Maier et al. (2010)
M12	Article by Mettler (2012)

MM-AND	Maturity Model by Andriani et al. (2018)
MM-BER	Maturity Model by Berger et al. (2018)
MM-CHA	Maturity Model by Chaghooshi et al. (2016)
MM-FRO	Maturity Model by Froger et al. (2019)
MM-SLI	Maturity Model by Sliz (2018)
NCA	Necessary Condition Analysis
OS	Original Search
PPI	Process Performance Index by Rummler-Brache Group
QCA	Qualitative Comparative Analysis
RBV	Resource-based View
REMMAP	Rethinking & Enhancing Maturity Models' Actual Potential
RQ	Research Question
S10	Article by Solli-Sæther/Gottschalk (2010)
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SIMMI 4.0	System Integration Maturity Model Industry 4.0
SOA	Service Oriented Architecture
SOAMM	Service-Oriented Architecture Maturity Model
SQ	Sub-research Question
V10	Article by van Steenbergen et al. (2010)

Part A. Synopsis

The dissertation at hand consists of seven papers published since 2018 that address the domain of maturity model research. The following synopsis provides an overview of the thesis, enabling readers to (1) perceive the underlying coherent piece of research, (2) understand the relations between the different essays, and (3) gain easier access to the individual articles. However, the synopsis not only outlines the conducted research, but also synthesizes the single pieces by introducing an artifact, namely the framework REMMAP, to accompany future designs and improve released models.

1 Do We Need More Research About Maturity Models?

To withstand today's competitive pressure triggered by increasing market dynamics, technological progress, and economic uncertainties, organizations need to continuously adapt and evolve their capabilities and processes. For example, the impact of digital transformation (Bley et al., 2021; Kraus et al., 2022; Matt et al., 2015) and the subsequent need for process changes have led companies to invest continuously in their business processes. By 2019, according to a survey by Harmon and Garcia (2020, p. 28), 62 % of the companies have already scheduled up to $500,000 for business process work. The remaining 38 % have projected more than $500,000 to remain competitive in the future (Harmon & Garcia, 2020, p. 28). In addition to digitalization, the COVID-19 pandemic – as one of the greatest organizational challenges of recent years – has once again highlighted the particular relevance of robust and competitive business processes (e.g., Dwivedi et al., 2020; Fortune Business Insights, 2021; Ozbiltekin-Pala et al., 2022; van Looy, 2021). To provide guidance for process changes, numerous management tools, such as business process maturity models (BPMMs), have been developed (Kerpedzhiev et al., 2020; Recker & Mendling, 2016; van Looy et al., 2024). Maturity models are tools to support organizational transformation and capability renewal by initiating and facilitating change in the long term (Colli et al., 2019; Felch, 2023; Mettler, 2010; Solli-Sæther & Gottschalk, 2010; Trautmann, 2021). They can serve three purposes: (1) descriptive, to identify the current state, (2) prescriptive, to map a development path, and (3) comparative, to benchmark capabilities within and across organizations (Felch et al., 2019; Pöppelbuß & Röglinger, 2011). The practical interest in maturity models also led to attention within the scientific community. The publication of newly developed models, especially BPMMs (e.g., Bley, 2021a, p. 7; Couckuyt & van Looy, 2020; dos Santos-Neto & Costa, 2019; Kerpedzhiev et al., 2020; Pereira & Serrano, 2020; Tarhan et al., 2016; van Looy et al., 2017), has increased steadily in recent years (e.g., Bley, 2021b; dos Santos-Neto & Costa, 2019; Gökşen & Gökşen, 2021; Pereira & Serrano, 2020; van Hillegersberg, 2019; Wendler, 2012).

Two kinds of BPMMs can be distinguished (Smajli et al., 2024): (1) models that address business processes in general[1] and (2) models that have been developed for a specific business process, e.g., supply chain or logistics management[2]. Logistics processes focusing on customer delivery have attracted particular attention within organizations as they reportedly have a greater impact on performance than other processes (McCormack et al., 2008). This is reinforced by the digital transformation's effects on logistics processes (e.g., Glistau & Coello Machado, 2018; Herold et al., 2021; Krowas & Riedel, 2019; Nicoletti, 2018, p. 4; Strandhagen et al., 2017). Back in 2018, released maturity models in the area of digitalization focused mainly on the manufacturing process, whereas models for the delivery process were lacking (Asdecker & Felch, 2018). This motivated the following research question (RQ):

RQ1: How should a maturity model be designed to assess the delivery process of manufacturing companies with regard to digitalization?

To contribute to this research question, the author of this dissertation presented the so-called Delivery Process Maturity Model 4.0 (DPMM 4.0) (Asdecker & Felch, 2018). Seizing on the particular relevance of delivery processes to organizational performance (McCormack et al., 2008), the

[1] E.g., Andriani et al. (2018), Jochem et al. (2011), or Rosemann and de Bruin (2005).
[2] E.g., Battista et al. (2012), Mendes et al. (2016), or van Landeghem and Persoons (2001).

model complemented previous contributions dealing with the manufacturing process (Asdecker & Felch, 2018). The model's peculiarities are, among others, its flexibility of the modeling architecture and the comprehensive model documentation (e.g., Gökalp & Martinez, 2022; Winkelhaus et al., 2022). The DPMM 4.0 was developed to the authors' best knowledge and subsequently published in the Journal of Modelling in Management in 2018 (Asdecker & Felch, 2018). To validate the DPMM 4.0, Felch et al. (2018) relied on a single case study that was likewise published as part of the NOFOMA conference proceedings. After its release, the model received wide recognition from business practice and the scientific community. Feedback provided after the DPMM 4.0 application at a leading multinational manufacturer of electric equipment was consistently positive (Felch et al., 2018). In particular, the assessment's scope, customizability, and accuracy were highlighted (Felch et al., 2018). Furthermore, the article published in the Journal of Modelling in Management was awarded the 2019 Emerald Literati Award in the 'highly commended' category (Emerald Publishing). In subsequent years, the paper was recognized by the scientific community, being cited more than 100 times so far (as of January 2024, Google Scholar: 147), and thus achieving the status of a 'well-cited' paper (Recker & Mendling, 2016). In light of this outside perspective, the work can actually be considered successful and the researchers involved could be satisfied with their contribution.

Mission Accomplished!?

The completion of (1) model development, (2) application, and (3) validation ('research with maturity models', cf. Wendler (2012, pp. 1330–1331)) provided an opportunity to reflect on the (own) research experience. This kind of retrospective analysis is an essential but often neglected part of research endeavors (McFadyen & Rankin, 2016) and a prerequisite for change and/or improvement as well as for the continuous development of research domains. Several researchers, e.g., Boud et al. (1985, p. 19) or Reymen (2001, p. 19), have already emphasized the relevance of reflection, while Cattaneo and Motta (2021, p. 186) pinpointed "[...] that experience per se is not enough; to learn, one needs to reflect on experiences". Reflection is referred to as "[...] the process of stepping back from an experience, to ponder, carefully and persistently, its meaning to the self through the development of inferences" (Daudelin, 1996, p. 39). Schön (1983, pp. 54–55, 61) distinguishes three types of reflection: (1) reflection-in-action, (2) reflection-on-action, and (3) reflection-on-practice (see Table 1, based on Schön (1983, pp. 54–55, 61), Reymen (2003, pp. 4–7), and Cattaneo and Motta (2021, pp. 186–188)).

	Reflection-in-action	**Reflection-on-action**	**Reflection-on-practice**
	Reflection while artifact design	Reflection after artifact design	Reflection after artifact designs
Who?	Individual or team	Individual or team	Individual or team
When?	Ex ante	Ex post	Ex post
What?	Element(s) of artifact design	Single artifact design	Multiple artifact designs

Table 1. Overview of the different reflection types

The most suitable type for reflecting on the released DPMM 4.0 is the reflection-on-action, as (1) it was conducted ex post and (2) a single artifact was designed. As outlined by Reymen (2003), possible questions for a reflection-on-action include, among others, 'Are the current design strategy and design methods appropriate for the problem?' or 'Are the essential problems being solved or is time being waste on irrelevant aspects?'. The process typically results in an expanded knowledge base, which, in turn, can lead to changes in assumptions, behaviors, and practices (Cattaneo & Motta, 2021; Daudelin, 1996; McFadyen & Rankin, 2016; O'Hanlon, 1994). This affects future research phases, allowing reflections to be perceived by other researchers (O'Hanlon, 1994).

To initiate such a process and to reflect on the own research (Asdecker & Felch, 2018; Felch et al., 2018), taken-for-granted assumptions and beliefs of maturity models were questioned and different possibilities of model design were addressed as recommended by Reymen (2003). Although self-criticism is not easy, the reflection of the works showed that the research's theoretical and managerial contributions could be subject to criticism. Two points should be highlighted: (1) a lack of justification for the underlying model structure and (2) missing evidence for the influence of the model content on business performance. Like many maturity models, DPMM 4.0 is based on the central premise that organizational development follows a predefined path (Asdecker & Felch, 2018). So far, the existence of such a pattern is not supported by empirical evidence. Furthermore, the model content, i.e., the attributes of the dimensions and elements of the DPMM 4.0, was derived using relevant literature and an online survey (Asdecker & Felch, 2018). However, empirical evidence confirming the influence of these attributes on business performance was not considered in the selection of the model content.

While the aforementioned points of criticism explicitly refer to the DPMM 4.0, several authors have raised similar concerns about BPMMs in general. The analysis by Röglinger et al. (2012, p. 338) indicated that "[...] all models outline a single path of sequenced stages". Moreover, van Looy et al. (2017, p. 479) criticized the underlying structure of predetermined organizational growth and called for "[...] more research to verify how they can be improved in a more dynamic way instead of a static, one-size-fits-all roadmap that current BPMMs present [...]". Additionally, the usefulness of some BPMMs is repeatedly questioned (Mettler, 2010; Tarhan et al., 2016), which can be attributed, among others, to the selection of model content. Various researchers, including van Steenbergen et al. (2010) and Röglinger et al. (2012), therefore suggest considering 'critical success factors' to derive the model content.

So What?

The comparison of the DPMM 4.0 reflection with the literature showed that the points of criticism identified in one's own research have previously been addressed in the context of BPMM research. It should be noted that despite the existence of some criticism, the literature lacked systematic meta-studies to guide a research cycle and improve future model designs (e.g., Albliwi et al., 2014; Tarhan et al., 2016; Wendler, 2012). This background, and in light of the models' potential to foster organizational change, led to the second research question that this dissertation addresses:

RQ2: Which points of criticism are inherent in BPMMs with regard to the design and publication process that limit the models' usefulness and applicability and how can these be overcome?

Wendler (2012) distinguishes two fields of research: (1) research with maturity models and (2) research about maturity models (see Figure 1, based on Wendler (2012, pp. 1330–1331)).

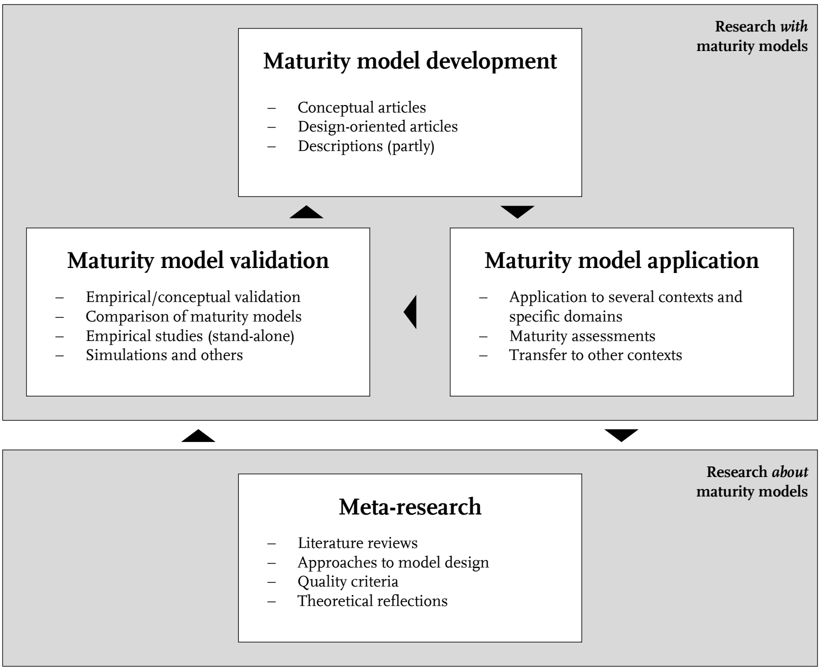

Figure 1. Fields of maturity model research

The former comprises the research cycle consisting of model development, application, and validation. The latter addresses meta-research aimed at a deeper understanding of research practices. This includes contributions focusing on conceptual considerations and their implications for maturity models. Both fields are interrelated. Research about maturity models provides the knowledge base to guide maturity model design and can thus increase the research's quality and rigor. Vice versa, research with maturity models, i.e., a completed research cycle, may lead to new insights that serve as an extension of the knowledge base.

The dissertation at hand contributes to both. Answering the first research question involves completing a research cycle, hence, it relates to research with maturity models. The second research question adds to research about maturity models. The dissertation's contribution is twofold: First, the released DPMM 4.0 can accompany changes in the delivery process due to the digital transformation and thus be useful for various model stakeholders (Article I and II, see Table 2). Second, a new artifact is proposed: the REMMAP framework. REMMAP is introduced in chapter 3 of this synopsis and synthesizes the findings published in the five papers that focus on research about maturity models (Article III–VII, see Table 2). It is intended to raise researchers' awareness of the models' points of criticism to accompany forthcoming research cycles and refine released model designs. It can further guide reviewers and editors in their demanding and responsible task of screening submitted works. Likewise, it provides model users with a comprehensive overview of points of criticism, enabling them to efficiently decide which model to apply. The findings will help improve future maturity models to better address the current hurdles in terms of usefulness and applicability and thus be of greater value to users.

The remainder of the synopsis is structured as follows: The next chapter highlights the relation between the different essays and, by relying on a concept-centric approach, the course of the investigation is outlined. Based on the implications, the framework REMMAP is proposed. In the following, its applicability is demonstrated by referring to the released DPMM 4.0. The synopsis concludes with a summary of the key results, implications for maturity model stakeholders, limitations, and future research avenues.

2 Highlighting Points of Criticism to Foster Change Within the Maturity Model Community

Between 2018 and 2023, seven papers were published that contribute to the two research questions derived in the previous section (see Table 2).

ID	Author(s)	Title	Outlet	RQ
I	Asdecker/ Felch	Development of an Industry 4.0 Maturity Model for the Delivery Process in Supply Chains*	Journal of Modelling in Management	1
II	Felch/ Asdecker/ Sucky	Digitization in Outbound Logistics – Application of an Industry 4.0 Maturity Model for the Delivery Process*	NOFOMA Conference	1
III	Felch/ Asdecker	Quo Vadis, Business Process Maturity Model? Learning from the Past to Envision the Future**	Business Process Management Conference	2
IV	Felch/ Asdecker	How to Make Business Process Maturity Models Better – Drawing on Design Science Research**	Pacific Asia Conference on Information Systems	2
V	Felch/ Asdecker	Advancing the Quality of Business Process Maturity Models**	Journal of International Business and Economics	2
VI	Felch	Do Procedure Models Actually Guide Maturity Model Design? A Citation Analysis**	Hawaii International Conference on System Sciences	2
VII	Felch/ Asdecker	Back to the Roots – Investigating the Theoretical Foundations of Business Process Maturity Models**	Business Process Management Conference	2

Legend: *research with maturity models, **research about maturity models

Table 2. List of publications related to the research questions

The first two articles (I and II) can be considered the motivation to further advance the domain of maturity models. Papers III to VII highlight three points of criticism regarding the design and publication process of maturity models. Specifically, the first three contributions (III to V) address the criticism of the models' quality and usefulness. By considering the underlying model issues, an initial proposal for overcoming those hurdles is derived. Article VI focuses on the criticism of the model design process, whereas paper VII refers to the criticism of the models' foundation. The implications of those two publications complement the preliminary proposal and result in a new artifact to guide forthcoming research cycles and further advance released maturity models (REMMAP framework, see chapter 3). Figure 2 illustrates the described relations among the publications.

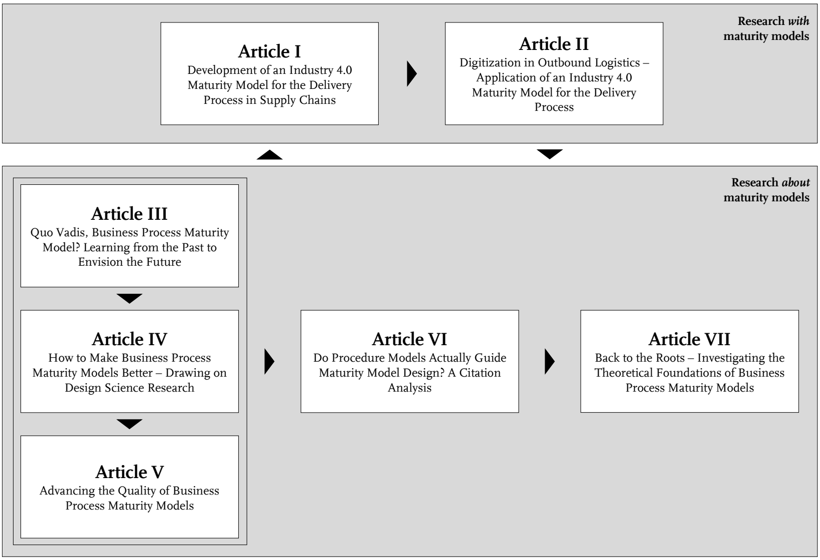

Figure 2. Relations between the publications

Instead of summarizing the individual papers, a concept-centric approach, as suggested by Webster and Watson (2002), is applied in the remainder of this synopsis. That is, the following sections address the points of criticism of (1) the models' quality and usefulness, (2) the model design process, and (3) the models' foundation. Besides, the course of the investigation is outlined by focusing on the core arguments and findings. The following section focuses on the first point of criticism, the doubts about the quality and usefulness of maturity models.

2.1 The Quality and Usefulness of the Models[3]

"[...] a number of available models appear to be 'power-point deep' in that they are proprietary in nature, have not been rigorously developed and tested, and are not supported by tools that enable them to be applied within a wide range of organizations."

de Bruin and Rosemann (2007, p. 644)

"Due to the large number of existing maturity models, the question arises whether high quantity goes along with high quality."

Pöppelbuß and Röglinger (2011, p. 1)

"[...] the many existing BPMMs are assumed to differ in quality."

van Looy (2014, p. 18)

"Although a rich set of maturity models for the BPM field exists, their use in practice is limited."

Tarhan et al. (2016, p. 129)

The previous quotes show that the quality and usefulness of BPMMs have been criticized by various authors (e.g., de Bruin & Rosemann, 2007; Pöppelbuß & Röglinger, 2011; Rosemann, 2015; Tarhan et al., 2016; van Looy, 2014, p. 18). However, these perspectives and opinions had to be considered anecdotal at this point. A systematic analysis to substantiate these appraisals had not been conducted. The dissertation at hand addressed this research gap. Following the premise that in academia the quality of a released model should be reflected in the quality of the publication outlet and in the article's citation count, an analysis of these two indicators was

[3] The following section refers to articles III to V.

conducted. The investigation was guided by the following sub-research question (SQ):

SQ1: How do the existing BPMM publications perform in terms of two quality proxies, i.e., the journals' impact factors and the article's citation count?

On the one hand, to reduce sample and selection biases (Durach et al., 2017), the investigation relied on the papers identified by Tarhan et al. (2016), who conducted the most comprehensive literature review of BPMMs to date. They identified 61 relevant articles for the period from 1990 to 2014 (Tarhan et al., 2016). On the other hand, to consider the most recent publications, the search was extended using the same approach for the period from 2015 to 2019. Further 69 articles were classified as relevant. This led to a total of 130 BPMM papers released between 1990 and 2019, which were included in the aforementioned analysis of journal impact factors and citations. The results showed that most BPMM articles were neither published in higher-quality outlets nor cited as often as other BPM papers. This is in line with the appraisals of various researchers (e.g., de Bruin & Rosemann, 2007; Pöppelbuß & Röglinger, 2011; Rosemann, 2015; Tarhan et al., 2016; van Looy, 2014, p. 18; Wendler, 2012).

Although the reasons may be manifold, the findings indicated that the BPMMs to date did not, in all cases, address the requirements of reviewers, fellow researchers, and users. Previously raised issues of maturity models include, among others, methodological shortcomings in model design (e.g., de Carolis et al., 2017; Marx et al., 2012; Pereira & Serrano, 2020; Rosemann & de Bruin, 2005), insufficient model documentation (e.g., Albliwi et al., 2014; Becker et al., 2009; Maier et al., 2012; Pöppelbuß et al., 2011; van Looy et al., 2013), and unsatisfactory relevance to theory and practice (e.g., de Bruin & Rosemann, 2007; Patas et al., 2013; van Looy et al., 2013), affecting the model's transparency, replicability, and, ultimately applicability. In a broader sense, these issues refer to the most common scientific principles (Canadian Institutes of Health Research, Natural Sciences and Engineering Research, Social Sciences and Humanities Research Council of Canada, 2016; Deutsche Forschungsgemeinschaft, 2019; National Academy of Sciences, 2009; UK Research Integrity Office, 2009), which are decisive criteria of peer-review processes.

This finding, along with the fact that criteria supporting model design and publication are considered important in literature (e.g., Wendler, 2012), motivated the derivation of an initial proposal to guide future model designs and enhance released BPMMs. Based on relevant literature, four overarching dimensions that are further differentiated into several units of analysis[4] were identified.[5] First, the dimension 'methodological design aspects'[6] comprised:

- Research guiding methodology,
- Appropriate literature,
- Development method,
- Established maturity models[7],
- Evaluation method,
- Evaluation criteria,
- Application method, and
- Application criteria.

Second, the dimension 'model content scope' reflects the peculiarities of the research area. Therefore, factors that have an evidence-based impact on organizational performance need to be derived individually and thus constitute the single units of analysis. Generally speaking, the unit of analysis can be referred to as 'area-specific content factors'. Articles III and V

[4] The total number of units of analysis depends on the quantity of units of analysis in the second dimension, model content scope, as these have to be derived area-specifically.

[5] Due to the synthesis of articles III to V, minor changes have been made to the original wording of some dimensions and units of analysis to achieve a better consistency between them and to provide little room for interpretation. The modifications are highlighted by footnotes wherever needed. The content, however, remains unaffected.

[6] By merging eight units of analysis, the name of the dimension has been changed to 'methodological design aspects' to better reflect the range of units of analysis.

[7] The original paper referred to this unit of analysis as 'basic maturity models' (Felch & Asdecker, 2020a). However, to limit the room for interpretation and better reflect the content of the unit of analysis, it has been renamed in 'established maturity models' in this synopsis.

provide an example of how to derive the individual units of analysis for the area of business process management (BPM), which are as follows:

- Organization,
- Supply chain integration,
- Process,
- IT, and
- Employees.

Third, the dimension ‘evolutionary ability’ consisted of:

- Model components for change[8] and
- Parameters of change.

Fourth, the dimension ‘model documentation’ contained:

- Current model need or new opportunity[9],
- Intended model purpose,
- Basic components of maturity models,
- Components of descriptive models, and
- Components of prescriptive models.

This proposal was an initial effort to (1) support designers in releasing transparent and replicable maturity models and (2) guide reviewers and editors in screening submitted works. In the further course of the dissertation project, when considering and verifying other points of criticism, this preliminary proposal was further refined by additional dimensions and/or units of analysis. This led to the design process, as reported in more detail in the following section.

8 The original paper referred to this unit of analysis as ‘model components’ (Felch & Asdecker, 2022a). To avoid the risk of confusion with the unit of analysis ‘basic components of maturity models’, the focus of the dimension is emphasized in the name of the unit of analysis by changing it to ‘model components for change’.

9 The original paper referred to this unit of analysis as ‘real-world problem’ (Felch & Asdecker, 2020a). To avoid misconception, this unit of analysis has been renamed as ‘current model need or new opportunity’.

2.2 The Design Process of the Models[10]

"Whilst maturity models are high in number and broad in application, there is little documentation on how to develop a maturity model that is theoretically sound, rigorously tested and widely accepted."

de Bruin et al. (2005, p. 3)

"The constant publication of new maturity models for often fairly similar applications however suggests a certain arbitrariness. The authors only rarely reveal their motivation and the development of the model, or their procedural method and the results of their evaluation."

Becker et al. (2009, p. 214)

"Further criticism refers to the multitude of almost identical maturity models, the dissatisfactory documentation of the design process, and a non-reflective adoption of the CMM blueprint [...]"

Pöppelbuß and Röglinger (2011, p. 4)

"[...] most of the existing MMs lack a solid theoretical foundation and/or are derived based on an arbitrary design method."

Caiado et al. (2021, p. 4)

Statements such as those by de Bruin et al. (2005) or Becker et al. (2009) and previously scarce literature served as motivation for various researchers to develop domain-specific methodologies, namely procedure models[11]. Such guidelines aim to support designers in creating transparent and substantiated maturity models and can be applied irrespective of the research area. An evaluation of the developed artifacts with regard to their achievement of objectives has been called for in literature (e.g., Becker et al., 2009; de Bruin et al., 2005), but has not yet been conducted. Almost a decade after publishing those guidelines, criticism regarding the design process was again voiced (e.g., de Carolis et al., 2017; Marx et al., 2012;

10 The following section refers to article VI.

11 Procedure models such as those by Becker et al. (2009), de Bruin et al. (2005), Maier et al. (2012), Solli-Sæther and Gottschalk (2010), or van Steenbergen et al. (2010).

Pereira & Serrano, 2020), especially in the case of models focusing on digitalization and Industry 4.0 (e.g., Caiado et al., 2021; Nottbrock, 2021). These observations motivated the initiative to evaluate the impact of the procedure model articles on the scientific community. This led to the following sub-research question:

SQ2: Are the procedure model articles considered for their main research focus, i.e., to accompany the model design process?

A citation context analysis was applied to examine the impact of five procedure model articles (Becker et al., 2009; de Bruin et al., 2005; Maier et al., 2012; Solli-Sæther & Gottschalk, 2010; van Steenbergen et al., 2010). The focus was placed on extracting the content to which the citing author(s) refer and classifying these in-text citations according to their respective purpose. Until 2022, the procedure model articles have achieved a high number of citations, for example, the article by de Bruin et al. (2005) was referred to 354 times. Taking a closer look at the classification of in-text citations, it became apparent that the articles were most frequently referenced for other reasons, e.g., model components, model purposes, or criticism regarding maturity models. The minority of in-text citations was assigned to the category that uses the articles for their main research focus, i.e., the procedure model for model design.

To further gain an understanding of the application frequency of procedure models in model design, 24 digitalization and Industry 4.0 models (Caiado et al., 2021) were analyzed, of which five refer to a procedure model (Asdecker & Felch, 2018; Rübel et al., 2018; Schumacher et al., 2016; Scremin et al., 2018; Weber et al., 2017). This led to two findings. First, scientifically recognized methodologies for model design are rarely applied. Second, whenever a methodology is used, a procedure model is chosen.

The analysis of 25 BPMMs provided a similar result (Felch & Asdecker, 2022a). Two models were designed using procedure models (Berger et al., 2018; Sliż, 2018) and one model was created by relying on a generic research methodology, namely the design science research (DSR) paradigm

(Zwicker et al., 2010). Thus, it can be concluded that the number of maturity models designed with a research guiding methodology is a lot lower than the number of articles published so far. Therefore, the impact of the procedure model articles on the actual model design process can, at best, be considered moderate.

In general, the disclosure of the research methodology leads to a more rigorous and transparent research process (Rosemann & Vessey, 2008), which in turn is an indicator of reproducibility and replicability (Aguinis et al., 2018; Campbell et al., 2014). For this reason, most common scientific principles (Canadian Institutes of Health Research, Natural Sciences and Engineering Research, Social Sciences and Humanities Research Council of Canada, 2016; Deutsche Forschungsgemeinschaft, 2019; National Academy of Sciences, 2009; UK Research Integrity Office, 2009) that guide peer-review processes contain the application of suitable methodologies and methods. To highlight the particular relevance of a research guiding methodology and to further address the issue of the arbitrary design process, the preliminary proposal (see section 2.1) was extended by a fifth dimension, 'scientific grounding' with the unit of analysis 'research guiding methodology'. The new dimension is intended to reflect the rationale underlying the conducted research.

Another notable point of criticism refers to the perspective through which maturity models are considered, which is outlined in the next section.

2.3 The Foundation of the Models[12]

"Moreover, our analysis suggests that studies on maturity models seldom refer to theories or theoretical statements of relationships (i.e., causal explanations or testable propositions)."

Becker et al. (2010, p. 6)

[12] The following section refers to article VII.

"Still, most of the maturity models are being developed based on the practices and lack a theoretical foundation."

Wißotzki and Koç (2014, p. 323)

"Although business process maturity models (BPMMs) turn out to be important aids for organisations, they are frequently criticised because many models exist without a theoretical foundation."

van Looy (2014, p. 1)

"One of the most important points of criticism is the fact that existing maturity models often lack a theoretical basis or empirical evidence to 'proof' the significance and accuracy of prediction."

Andersen et al. (2020, p. 262)

Maturity models are based on the assumption that organizational change proceeds along predictable patterns, which implies recourse to some kind of theory. In contrast, however, statements by various researchers point to a weak theoretical foundation of maturity models (e.g., Andersen et al., 2020; Becker et al., 2010; de Carolis et al., 2017; Lahrmann et al., 2011; Lasrado, Vatrapu, & Andersen, 2016; Marx et al., 2012; Mettler, 2010; Patas, 2015; Solli-Sæther & Gottschalk, 2010; Szelagowski & Berniak-Woźny, 2020; Wißotzki & Koç, 2014) and BPMMs in particular (e.g., Niehaves et al., 2013; van Looy, 2014). The theoretical foundation is understood as the perspective used to conduct the research study. The previous quotes and the fact that the theoretical foundation is an essential criterion for high-quality papers (Bornmann et al., 2008; Straub, 2009; Sutton & Staw, 1995) prompted a systematic analysis to examine whether a lack of theoretical grounding prevails in previous models, leading to the following sub-research question:

SQ3: Which theoretical approaches are considered in BPMM literature so far?

To contribute to this question, 25 BPMMs published between 1990 and 2019 were analyzed regarding their theoretical foundation. The findings indicated that the vast majority of scholars drew on existing models and adopted their structure. Only one article referred to the stage theory for model development (Chaghooshi et al., 2016). This confirmed that most of the BPMMs lack a theoretical foundation, which prompted a review of related BPMM literature that addresses the underlying model assumptions. However, up to this point, the literature had hardly dealt with these, resulting in the addition of only two other approaches, namely convergence and process life-cycle theory.

Altogether, three theories were identified: (1) stage theory, (2) convergence theory, and (3) process life-cycle theory. In addition, their suitability as a foundation for maturity models was evaluated. The findings indicated that neither of these approaches is appropriate as model basis. The reflection of the origin and core statements of convergence theory resulted in its exclusion. Numerous criticisms focusing on the other two theories led equally to doubts about their suitability. Both theories (1) assume linear relationships, (2) are static, and (3) point to an absolute end state. Using abductive reasoning, it was outlined that these assumptions do not adequately reflect the reality of organizations and, at the same time, are in line with three fundamental criticisms of maturity models.

Unlike other domains that require a theoretical foundation (Bornmann et al., 2008; Straub, 2009), this has rarely been taken into account for maturity models. However, to adequately reflect reality within the model structure and thus improve the model's explanatory power and enable more informed and efficient decision-making, it is necessary to place particular emphasis on the relevance of the theoretical foundation in this domain as well. Therefore, another unit of analysis is added to the previously introduced dimension 'scientific grounding' (see section 2.2), namely the 'theoretical foundation undertaken'.

To conclude, the initial proposal (see section 2.1) was refined by considering and verifying two additional points of criticism related to the model design and publication process, resulting in a new artifact that is presented in the following section.

3 Proposing an Artifact to Further Improve Research Cycles

This section introduces the artifact REMMAP (see section 3.1) before its applicability is demonstrated by referring to the released DPMM 4.0 (see section 3.2).

3.1 Getting Started With the Framework REMMAP

The proposed artifact constitutes a normative framework called REMMAP (Rethinking & Enhancing Maturity Models' Actual Potential) that can serve as a template for design decisions considered by model stakeholders to better address the current challenges. The artifact's target audience, besides reviewers and editors that refer to it to screen submitted articles, is primarily model designers, such as fellow researchers, consultants, industry experts, or government representatives. The framework REMMAP consists of five dimensions with 17 units of analysis to (1) assist in the design of new maturity models and (2) improve released models (see Table 3). It can be applied once or on a recurring basis, e.g., to create a maturity model and to revise it over time to maintain the model's accuracy and relevance.

The suggested artifact was created in the context of BPMMs. However, it is generic in nature and can, therefore, be applied to maturity model research regardless of the area under study. It adds to the field of research about maturity models and thus expands the current knowledge base that can inform future and completed research cycles of maturity models (cf. Figure 1).

Dimension	Unit of analysis
Scientific grounding	• Research guiding methodology • Theoretical foundation undertaken
Methodological design aspects	• Appropriate literature • Development method • Established maturity models • Evaluation method • Evaluation criteria • Application method • Application criteria
Model content scope	• Area-specific content factors
Evolutionary ability	• Model components for change • Parameters of change
Model documentation	• Current model need or new opportunity • Intended model purpose • Basic components of maturity models • Components of descriptive models • Components of prescriptive models

Table 3. Proposed framework REMMAP[13]

Apart from proposing solutions to specific concerns or problems, research aims to evaluate these artifacts (Kothari, 2004, pp. 1–2; Rosemann & Vessey, 2008). This ex post analysis is intended to provide information on whether the problem has actually been solved or improvements may be observed and can be an impetus for subsequent iterations to refine the artifact. To evaluate the proposed framework, the (own) research, namely the DPMM 4.0, is revisited, which is outlined in more detail in the following section.

13 For further details on dimensions, units of analysis and their specifications refer to articles III–VII (see Part B).

3.2 Applying REMMAP by Returning to the Point of Origin

This section demonstrates the application of the novel artifact using the released DPMM 4.0. Likewise, it serves as an example of how to assess a designed maturity model by model stakeholders, e.g., the designer(s) themselves, reviewers and editors, or model users.

For reasons of clarity and comprehensibility, the artifact application is presented in tabular form according to the five REMMAP dimensions. The tables' first and second columns contain the respective unit of analysis and its specification, i.e., the guidelines provided by REMMAP. The third column briefly describes the information contained in the publication of the model under study for the respective unit of analysis. In the case of DPMM 4.0, the information originates from the two publications by Asdecker and Felch (2018) and Felch et al. (2018). The fourth column provides the assessment result, i.e., the extent to which the guidelines specified by REMMAP are fulfilled by the model under study. This study distinguishes three states: (1) fully considered (●), (2) partly considered (◑), or (3) not considered (○). States (2) and (3) represent room for improvement. In the following, the DPMM 4.0 is assessed using the five REMMAP dimensions (see Tables 4–8).

Scientific Grounding

Based on the assessment, the DPMM 4.0 only partially fulfills the REMMAP guidelines (see Table 4). While it was used a systematic six-step procedure as research guiding methodology, there is potential for improvement with regard to the theoretical foundation since the model structure, i.e., how the development of organizations proceeds, has not yet been theoretically embedded. Although it is acknowledged that firms can create competitive advantage, particularly through uniqueness and heterogeneity, a linear path was chosen to reach the predefined desirable end state. However, to pursue the premise, it is important to abandon the stage approach and instead opt for one that allows for several equally advantageous paths, e.g., the approach by Lasrado, Vatrapu, and Andersen (2016), and thus better represent reality.

Unit of analysis	Specification of the unit of analysis	DPMM 4.0 details provided	Considered?
Research guiding methodology	Maturity model-specific or generic procedure	Application of the maturity model-specific procedure model by de Bruin et al. (2005) for model design	●
Theoretical foundation undertaken	Generic or area-specific theoretical approaches	No indications of a theoretically embedded model structure	○

Table 4. Application of the REMMAP dimension 'scientific grounding' to the DPMM 4.0

Methodological Design Aspects

The assessment results of the dimension 'methodological design aspects' show that the REMMAP guidelines are almost fulfilled (see Table 5). As part of the model design, relevant literature that complies with scientific standards was taken into account. Adequate model aspects from an established maturity model were tailored to the DPMM 4.0. Moreover, recommended methods were used for model development, evaluation, and application. Thus, the guidelines of these units of analysis are fully addressed. Room for improvement is identified for the units evaluation and application criteria. Evaluation criteria were derived based on non-English literature, resulting in a list that does not include all specified REMMAP criteria. Additionally, the criteria for application are not explicitly outlined within the publications. The ones implicitly mentioned are consistent with those specified. It remains unclear whether, for example, generality or impact on environment and user, were taken into account. In future publications, attention should be paid to an explicit enumeration of all items applied.

Unit of analysis	Specification of the unit of analysis	DPMM 4.0 details provided	Considered?
Appropriate literature	Relevant area-specific literature	Consideration of relevant scientific literature for model architecture and content as well as method application in various design phases	●
Development method	Literature review, case study, Delphi study, focus group, external feedback from practitioners, and/or expert interviews	Recourse to two methods for model development, namely a literature review and an online survey	●
Established maturity models	Leading area-specific maturity models	Derivation of the maturity stages by adjusting the established stages of SIMMI 4.0 by Leyh et al. (2016)	●
Evaluation method	Demonstration with a prototype, experiment with prototype or system, benchmarking, survey, expert interview, focus group, and/or case study	Test of model validity and reliability by using external feedback obtained via an online survey	●
Evaluation criteria	Method: ease of use, efficiency, generality, and operationality Model: completeness, fidelity with real-world phenomena, internal consistency, level of detail, and robustness	Model evaluation based on several literature-based criteria, i.e., comprehensibility, comprehensiveness, relevance, consistency, systematic structure, detailedness, conceptual reliability, and applicability	◑

Unit of analysis	Specification of the unit of analysis	DPMM 4.0 details provided	Considered?
Application method	Case study, field experiment, survey, expert interview, and/or focus group	Validation of the final model and demonstration of its applicability by conducting a case study within a multinational manufacturer	●
Application criteria	Applicability, effectiveness, efficiency, fidelity with the real-world phenomenon, generality, impact on artifact environment and user, and internal or external consistency	Model validation by using various literature-based, but not explicitly listed criteria, e.g., comprehensiveness, effectiveness, and efficiency	◑

Table 5. Application of the REMMAP dimension 'methodological design aspects' to the DPMM 4.0

Model Content Scope

Regarding the dimension 'model content scope', the DPMM 4.0 does not well reflect the REMMAP guidelines, indicating a potential lever to further improve the model's quality (see Table 6). Empirical evidence can be identified in the literature for some of the included approaches, but it was not systematically examined before adding the approaches as model content. Therefore, organizational development may not be effectively managed in some places.

Unit of analysis	Specification of the unit of analysis	DPMM 4.0 details provided	Considered?
Area-specific content factors	Factors with an evidence-based impact on organizational performance	Derivation of element content using relevant literature and an online survey	○

Table 6. Application of the REMMAP dimension 'model content scope' to the DPMM 4.0

Evolutionary Ability

The REMMAP guidelines are partially taken into account, yet minor room for improvement can be determined (see Table 7). Concerning model components for change, so far only the form has been addressed. Additional information regarding potentially necessary changes to the underlying assessment or decision methodology (functioning) would be helpful to sustain full model applicability. For the parameters of change, the initiator of change, e.g., model designer(s) and/or model users, is not provided, which can lead to a lack of responsibilities.

Unit of analysis	Specification of the unit of analysis	DPMM 4.0 details provided	Considered?
Model components for change	Form and functioning	Consideration of content-related and structural model changes due to domain or area-specific progress; no indications of changes in the assessment/ decision methodology	◑
Parameters of change	Frequency and initiator of change	Disclosure of a rule for the frequency of change; no statement about the initiator of change	◑

Table 7. Application of the REMMAP dimension 'evolutionary ability' to the DPMM 4.0

Model Documentation

Based on the assessment, the DPMM 4.0 reflects well the REMMAP suggestions (see Table 8). The originality of the new model and its relevance for academia and business practice has been demonstrated. The model purpose, the basic components, and the components for the descriptive purpose have been outlined. Nevertheless, in light of the prescriptive purpose, improvement potential regarding the associated components can be identified. A decision calculus for prioritizing derived improvement measures is provided, but is only defined in general terms. Target group-specific differences are not taken into account, thus, adjustments to improvement measures can only be handled individually, not systematically. Especially with regard to the creation of competitive advantages that sustain the organizational existence in the long term, the adaptation of improvement measures seems to be worthwhile.

Unit of analysis	**Specification of the unit of analysis**	**DPMM 4.0 details provided**	**Considered?**
Current model need or new opportunity	Assertion, literature review, review practitioner initiatives, expert interview, focus group, and/or surveys	Demonstration of the need for a new model by a comprehensive comparison of existing models and a digitalization initiative by a multinational manufacturer	●
Intended model purpose	Descriptive, prescriptive, or comparative	Explicit information about the model's purpose, namely descriptive, prescriptive, and comparative	●
Basic components of maturity models	Number of levels, descriptor for each level, generic description of the characteristics of each level, number of dimensions, number of elements for each process area, and description of each activity as it might be performed at each maturity level	Description of all basic components (e.g., five maturity stages, three dimensions, and fifteen elements)	●

Unit of analysis	Specification of the unit of analysis	DPMM 4.0 details provided	Considered?
Components of descriptive maturity models	Intersubjectively verifiable criteria for each maturity level and level of granularity and target group-oriented assessment methodology	Disclosure of all necessary components for descriptive purposes due to comprehensive appendix (e.g., the flexibility of model architecture for organization-specific model adaptation)	●
Components of prescriptive maturity models	Improvement measures for each maturity level and level of granularity, decision calculus for selecting improvement measures, and target group-oriented decision methodology	Derivation of the improvement measure based on the provided characteristics of the elements; further information on the general decision calculus	◑

Table 8. Application of the REMMAP dimension 'model documentation' to the DPMM 4.0

Concluding Remark

The demonstration of the framework REMMAP shows that potential for improvement exists for the DPMM 4.0, especially regarding two units of analysis: theoretical foundation undertaken and area-specific content factors. The identified potentials can motivate a revision of the DPMM 4.0, which in turn may enhance the model's quality and thus additionally increase its application frequency and dissemination. By doing so, the released model could further gain in quality and become even more disseminated in the future.

As can be seen from the demonstration, the artifact application resembles a gap analysis that identifies deviations of the status quo from the intended state and derives possible areas for action to address those gaps. Furthermore, the artifact can be valuable in comparing various maturity models regarding their characteristics and selecting an appropriate one. Thus, the artifact's purpose is reminiscent of the purpose of maturity models, namely descriptive, prescriptive, and comparative.

This section synthesizes the dissertation's individual pieces of research by proposing REMMAP and demonstrating its applicability. To conclude the dissertation's investigation, the following section highlights the implications for various model stakeholders and points out future research opportunities.

4 Making Progress – But Way to Go

To summarize, the continuous development of capabilities and the ongoing transformation of business processes are crucial for the long term survival of a company. Maturity models can support organizations facing this challenge. In addition to the digital transformation and the process' impact on organizational performance, a focus has been placed on the delivery process, i.e., a specific business process (e.g., García-Bañuelos et al., 2017). Despite its relevance, models concerned with the manufacturing process were predominantly published until 2018, while models for the delivery process were absent. The dissertation at hand contributed to this research gap by developing, applying, and validating a respective model, namely the DPMM 4.0. Two papers address the aforementioned research cycle, guided by de Bruin et al. (2005)'s procedure model (Asdecker & Felch, 2018; Felch et al., 2018). The DPMM 4.0 can be used to identify the current state of digitalization efforts within the delivery process and to derive improvement measures to accompany an organizational development path.

Apart from the model release as a response to practical interest, the reflection of one's (own) work showed that the research contributions can be subject to criticism. Similar points have already been raised in the context of BPMMs in general. However, the voiced criticisms were anecdotal in nature and not systematically investigated back in 2019. Altogether, five studies responded to this research gap by (1) highlighting prevailing points of criticism of BPMMs that are inherent in the design and publication process, (2) systematically verifying the anecdotal evidence of these issues, (3) identifying reasons for the points of criticism, and (4) providing proposals to better address the current challenges (Felch, 2023; Felch & Asdecker, 2020a, 2020b, 2022a, 2022b). To contribute to BPMM research, the dissertation at hand presents a normative framework REMMAP that can be used by various stakeholders, such as model designers, reviewers, editors, or model users, to assess designed maturity models at different phases (including design, publication, and dissemination phase) and identify their strengths and shortcomings.

What Can Different Stakeholders Take Away From These Findings?

The dissertation at hand is the first to apply the reflection-on-action approach to the domain of maturity models. The approach contributes to two purposes of research, namely the creation of knowledge and the opportunity to change things for the better (Aityan, 2022, p. 6; Clough & Nutbrown, 2012, p. 14; Ghauri et al., 2020, p. 11; Kothari, 2004, p. 1).

On the one hand, within the scope of this dissertation, a tool was designed that can guide the organizational transformation process of the delivery process in the long term. Due to the successfully completed research cycle, the DPMM 4.0 is ready to use. Users will benefit from detailed documentation of the design and the flexibility of the model architecture, which allows for adapting the model to organization-specific processes. Furthermore, the papers can serve as a starting point for stakeholders that consider a model application. The overview of previous models with a focus on digitalization is complemented by their application scope and weaknesses to enable an efficient model selection.

On the other hand, the dissertation highlights points of criticism of BPMMs and thus creates awareness and a better understanding of this issue, which in turn forms the basis for change. Taking a broader perspective, the work adds to the quality assurance in the domain of maturity models and strengthens the competencies of different model stakeholders. This dissertation's contribution is aimed at the following three stakeholders: (1) model designers, (2) model reviewers and editors, and (3) model users.

First, expanding the current state of BPMM research provides model designers with an overview of the latest trends in the field and enables them to build on identified shortcomings. Furthermore, addressing the BPMM points of criticism supports designers in becoming aware of these issues and considering appropriate strategies for overcoming them during model design. Applying the proposed artifact, analogous to the DPMM 4.0 assessment in section 3.2, can more effectively guide the design process of planning, conducting, and documenting, as well as subsequent publication and communication to the other stakeholders. Additionally, the chances of acceptance in higher quality outlets may increase, enabling the highest possible model application and dissemination rate. Besides, designers without academic background, e.g., consultants, industry experts, or government representatives, likewise benefit from the study results, as they can design more substantiated and reliable models by applying the proposed artifact.

Second, reviewers and editors benefit from the comprehensive review of recent BPMM articles, serving as reference for the current state when screening submitted research and enabling faster decisions on the papers' originality. Moreover, the novel artifact allows for a more thorough review of the rigor of the research process, comprehensive documentation of a model, and its accuracy and relevance. The artifact application to examine submitted works can similarly be conducted to the DPMM 4.0 assessment (see section 3.2). Reviewers and editors are able to screen more easily whether points of criticism have been deliberately considered in the BPMM submission. This can result in a faster review process for newly submitted BPMM articles, which speeds up the publication process. Consequently, all stakeholders will benefit from an accelerated publication of more meaningful work.

Third, this work supports model users, such as fellow researchers, consultants, or industry experts, in gaining an overview of released BPMMs, including their strengths and shortcomings, to enable more informed decisions when selecting an appropriate model. In addition, to identify a suitable model addressing areas other than BPM, users can compare the characteristics of those respective models by applying the proposed artifact (see section 3.2). In the long term, users also benefit from releasing more substantiated and transparent models, which are easier to apply. Future models will better overcome the hurdles identified, guide organizational decisions more effectively, and thus be of greater value to users.

Limitations to Be Considered

As with any work, the thesis at hand has limitations. This section refers to the ones that originate from the general setup and structure of this dissertation synthesized in this synopsis. More specific limitations concerning the individual articles have already been considered therein (see Part B).

First, since the person conducting the reflection was also involved in the research reflected (Asdecker & Felch, 2018; Felch et al., 2018), potential biases, such as confirmation bias[14], may have occurred. To counteract it, a systematic process by referring to Reymen (2003)'s reflection-on-action guiding questions was applied. Despite the limitation, the approach provides another way of generating knowledge that can not only change one's own behavior and perspective but may also be beneficial for the scientific community.

Second, the dissertation primarily draws on only three points of criticism regarding maturity models, while others may exist. This could limit the derived artifact's completeness. However, in light of the most common scientific principles (Canadian Institutes of Health Research, Natural Sciences and Engineering Research, Social Sciences and Humanities Research Council of Canada, 2016; Deutsche Forschungsgemeinschaft, 2019; National Academy of Sciences, 2009; UK Research Integrity Office, 2009) and prevailing literature of maturity models (e.g., Andersen et al., 2020; García-Mireles et al., 2012; Lasrado, Vatrapu, & Andersen, 2016; Proença & Borbinha, 2016; Wendler, 2012), the three considered appear to be particularly relevant. At the same time, this work is intended to serve as a motivator to verify other points of criticism, such as adequate communication of research findings to diverse stakeholders (e.g., Lasrado, Vatrapu, Kærsgaard, & Kjaer, 2016), and thus to provide appropriate (cross-area) solutions.

[14] The confirmation bias is defined as "[...] people's tendency to search for information that supports their beliefs and ignore or distort data contradicting them" (Peters, 2022, p. 1351).

Third, the second research question (RQ2) is answered solely on the basis of existing literature. As a result, not all relevant drivers may have been identified and additional dimensions and/or units of analysis would be required to adequately address them. Future studies should, therefore, complement the findings of this work with qualitative and/or quantitative approaches.

Apart from the limitations outlined, several intriguing research avenues arise from the research conducted so far. Three of these are briefly presented below.

Impetus for Future Research and Like-Minded Scholars

First, the artifact's applicability was demonstrated by referring to the released DPMM 4.0. Additional evaluations, such as using it for upcoming model designs, are needed to further assess its applicability and usefulness. These results can prompt subsequent refinements to the artifact. In addition, circumstances may change over time, e.g., due to new scientific insights affecting the proposed artifact. To sustain its accuracy and relevance, the artifact should be continuously revised, as is common with maturity models. Sticking with the long term perspective, it would be interesting to know to what extent the suggested artifact has shaped the academic discourse and led to changes in the sense of more transparent and substantiated maturity models. This leads to the following research guiding questions:

- How does the artifact perform in other evaluations in terms of applicability and usefulness?
- Which artifact modifications are necessary to maintain its relevance and accuracy in the long term?
- Which impact does the proposed artifact actually have on maturity model research and its stakeholders?

Second, further points of criticism have been raised in maturity model literature (e.g., Lasrado, Vatrapu, Kærsgaard, & Kjaer, 2016). These issues refer not only to the design and publication process but also to the application and dissemination of those models. The points of criticism considered so far stem from literature. Although crucial for the dissemination and success of the models, points of criticism from various model stakeholders, e.g., reviewers, editors, or users, have not yet been explicitly addressed. It would be worthwhile to know whether other points of criticism can be added to those examined and thus further extend the proposed artifact. Similar to this work, verifying the additional points and identifying their reasons is necessary to further substantiate upcoming models. Additionally, the question arises to what extent approaches to overcome those points of criticism already exist. This prompts the subsequent research guiding questions:

- Which other points of criticism with regard to (aside from) the design and publication process can be verified in the literature?
- Which points of criticism are perceived by other stakeholders and can be verified?
- Which suggestions can be provided to mitigate or eliminate the points of criticism?

Third, the linear and absolute nature of most maturity models contradicts the individual change of organizations (Felch & Asdecker, 2022b). Many of the released maturity models tend to be generic and are rarely customizable (e.g., Christiansson & van Looy, 2017; Felch et al., 2019; Lasrado et al., 2015; Patas et al., 2013; Schumacher et al., 2019). Against the background of the intended model purposes, it needs to be considered whether maturity models published so far can actually fulfill these purposes. The question arises whether, for example, a derivation of improvement measures from widespread best practices is appropriate or whether organization-specific models would actually be more appropriate. It seems like most models are mainly suitable for measuring the maturity of a sector or industry and for providing cross-sector or cross-industry comparisons. However, to serve the descriptive and especially the prescriptive purpose, organization-specific models are needed. To adequately support the organizations in their development, it could be particularly beneficial to focus on instructions for individual maturity models. Essential questions guiding future research are therefore:

- Can maturity models, in the way they are currently designed and released, fulfill the organizational objectives?
- Which guidelines can be provided to design organization-specific models?
- Which aspects need to be considered when designing sector- or industry-specific models?

The proposed research avenues are intended to guide researchers' future efforts toward certain aspects that will further advance the field of research about maturity models and, in particular, the research cycle. Referring to the question of whether more research on maturity models is needed, it can be stated that, in any case, more efforts are necessary to actually create a change for the better. In particular, normative research that provides guidelines, values, and recommendations is crucial to achieve this objective. With the seven articles enclosed (see Part B), the dissertation at hand can be considered a step in that direction.

5 References

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Part B. Publications

This part contains the seven published papers[15] that are part of the dissertation. Table 9 provides the articles' order listed in the following sections.

ID	Author(s)	Title	Outlet	RQ
I	Asdecker/ Felch	Development of an Industry 4.0 Maturity Model for the Delivery Process in Supply Chains	Journal of Modelling in Management	1
II	Felch/ Asdecker/ Sucky	Digitization in Outbound Logistics – Application of an Industry 4.0 Maturity Model for the Delivery Process	NOFOMA Conference	1
III	Felch/ Asdecker	Quo Vadis, Business Process Maturity Model? Learning from the Past to Envision the Future	Business Process Management Conference	2
IV	Felch/ Asdecker	How to Make Business Process Maturity Models Better – Drawing on Design Science Research	Pacific Asia Conference on Information Systems	2
V	Felch/ Asdecker	Advancing the Quality of Business Process Maturity Models	Journal of International Business and Economics	2
VI	Felch	Do Procedure Models Actually Guide Maturity Model Design? A Citation Analysis	Hawaii International Conference on System Sciences	2
VII	Felch/ Asdecker	Back to the Roots – Investigating the Theoretical Foundations of Business Process Maturity Models	Business Process Management Conference	2

Table 9. Overview of the enclosed publications

[15] Unlike the published version of the articles, minor changes within the dissertation at hand may occur in the layout and placement of figures and tables to improve readability. The articles' content, however, remains unaffected.

Article I. Development of an Industry 4.0 Maturity Model for the Delivery Process in Supply Chains

Authors. Björn Asdecker and Vanessa Felch

Publication Outlet. Journal of Modelling in Management

Reference. Asdecker, B., & Felch, V. (2018). Development of an Industry 4.0 Maturity Model for the Delivery Process in Supply Chains. *Journal of Modelling in Management, 13*(4), 840–883.

DOI. 10.1108/JM2-03-2018-0042

Honored with the 2019 Emerald Literati Award in the category 'highly commended paper' (Emerald Publishing)

Abstract.

Purpose. This paper aims to show that current Industry 4.0 maturity models primarily focus on manufacturing processes. Until now, research has been lacking with regard to outbound logistics, that is, the delivery process. This paper develops such a model.

Design/methodology/approach. Methodologically, this paper is grounded in design science research (DSR) and rigorously follows the model development guidelines presented by de Bruin et al. (2005). This work builds on current maturity models and original empirical research to populate and test the model.

Findings. The model appears to be applicable to describing the status quo of the digitization efforts in outbound logistics, developing a corporate vision for delivery logistics excellence and providing guidance on the development path.

Research limitations/implications. Thus far, the model has been applied only for a development stakeholder. For further validation, the authors are currently working on additional case studies to demonstrate the model's applicability.

Practical implications. The developed model provides guidance for the digitization of an important value-adding activity in supply chain management: the delivery process.

Originality/value. To the authors' knowledge, the proposed model is the first to explicitly consider the delivery process; therefore, it complements available approaches that focus on the manufacturing process. Moreover, the results show that the widely used Supply Chain Operations Reference model can serve as the basis for additional process maturity models.

Keywords. Logistics · Supply Chain Management · Value Chain

I.1 Introduction

The term supply chain management (SCM) was first coined by Oliver and Webber (1982) in a Booz Allen and Hamilton publication 35 years ago. Within their contribution, these authors broach the issue of a material flow instead of a functional silo perspective:

> [...] it views the supply chain as a single entity rather than relegating fragmented responsibility for various segments in the supply chain to functional areas such as purchasing, manufacturing, distribution, and sales.

Since then, many researchers have investigated the concept of SCM, thereby establishing the current theoretical and operational bases. Stock and Boyer (2009) attempted to develop a uniform agreed-upon definition within a qualitative study. Their main motivation was to provide common ground among researchers and practitioners to advance theory and practice. Accordingly, these authors define SCM as:

> The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction (Stock & Boyer, 2009, p. 706).

The task of achieving efficiency and customer satisfaction in a value-adding network of interdependent institutions is facilitated by information and communication technology (ICT) (Masteika & Čepinskis, 2015). Two recent advances in the field of ICT are of specific importance for SCM: the Internet of Things (IoT) and cyber-physical systems (CPS).

The IoT is a dynamic network infrastructure with self-configuring capabilities where both physical and virtual things have identities with intelligent interfaces that are seamlessly integrated in the information network. The IoT is the technological basis that enables the networking of and with things. The exchanged data can be analyzed and new insights can be gained. CPS merge informational and electronic components to form embedded intelligent systems that control themselves autonomously. Therefore, CPS may be defined "[...] as transformative technologies for managing interconnected systems between its physical assets and computational capabilities" (Lee et al., 2015, p. 18). Both the IoT and CPS are radically transforming business models and their resulting supply chains in a unique, unprecedented way, thereby triggering a fourth industrial revolution. This phenomenon is referred to as Industry 4.0. The unique characteristic of Industry 4.0 is its set of automated self-configuration, self-adjustment and self-optimization capabilities that allow for more agile and cost-efficient processes. Furthermore, increased customer satisfaction is obtained via smart connected products that pave the way for new data-driven value-adding services. Strong empirical and econometrical evidence links ICT capabilities (Bharadwaj, 2000; Brynjolfsson & Hitt, 2000) and supply chain maturity (McCormack et al., 2008) to business performance. Therefore, we stress the argument that current trends in the form of IoT and CPS will further increase productivity and commercial success.

Acknowledging these changes in the business environment, the demand for management concepts that reflect the emerging challenges and opportunities of the digital age ahead of us has increased. Therefore, the concept of SCM must become SCM 4.0. Hence, the tools and best practice processes that have been developed over the past 35 years need to be re-evaluated and refined. Adequate tools to identify and then build SCM 4.0 capabilities are maturity models. In general, maturity models describe typical patterns in the development of resources. All models are built on the hypothesis that organizational evolution follows a predictable stage-by-stage pattern (Isoherranen et al., 2015). Herein, each stage represents a certain level of maturity and later stages are superior to the earlier ones, with the highest level denoting excellence (Rao et al., 2003). Those maturity stages can be applied to various domains, e.g. business units or specific processes, which can be regarded as model dimensions (Fraser et al., 2002). Model dimensions represent a specific field of application. Knowing the maturity stage in the respective field of application is essential to identifying improvement potentials and stimulating a continuous improvement process (Isoherranen et al., 2015). Consequently, maturity models enhance organizational excellence and help firms to address increasing market dynamics.

In this context, this work aims to develop a theoretically grounded model for the delivery process of manufacturing companies, which has so far been neglected in the available literature despite its particular relevance. According to McCormack et al. (2008), the delivery process has a greater impact on business performance than other supply chain processes. Politis et al. (2014) highlighted the effect of logistics service quality on customer satisfaction in manufacturing companies' supply chains. Because competitive advantage "[...] rests on a firm's idiosyncratic and difficult-to-imitate resources [...]" (Teece et al., 1997, p. 513), the developed maturity model will provide not only a collection of best practices but also a flexible, customizable modeling architecture that is capable of taking into account the specific characteristics and peculiarities of an organization.

This study provides three key contributions. First, it reviews available maturity models with a specific Industry 4.0/SCM 4.0 perspective. Second, the developed model complements the available ones by focusing on the delivery process, which can be defined as all activities that are necessary to fulfill a customer order. Third, this work will thoroughly document both the scientific development process and the final maturity model (please refer to the Appendix). Most previous publications have focused on model development but lack full documentation, which limits the transferability of their results into practice. Providing such transparency may increase the vulnerability of the model to potential critiques. Nonetheless, we believe that comprehensibility and reproducibility are of greater importance.

The remainder of this article is structured as follows. Section I.2 provides the theoretical background, reviews Industry 4.0 maturity models and highlights the research gap that this paper addresses. Section I.3 describes the applied methodology and documents the model's development. Finally, Section I.4 provides a summary, discusses limitations, and offers suggestions for future research.

I.2 Theoretical Background and Literature Review

The theoretical foundations of maturity models include the resource-based view (RBV) of the firm in combination with dynamic capability theory (DCT). The RBV considers organizations as collections of resources. To create competitive advantage, resources must be valuable, rare, non-imitable and non-substitutable (Barney, 1986; Penrose, 1959). Resources can be either assets or capabilities. Tangible (e.g. buildings, machines) and intangible (e.g. brand reputation, organizational learning) assets are used and controlled by an organization. In this context, capabilities represent a set of skills exercised through organizational routines (Galbreath, 2005). DCT complements the RBV by acknowledging that market dynamics are constantly changing the requirements to achieve competitive advantages (Teece et al., 1997). Consequently, organizations require competences that respond to shifts in the business environment to maintain performance in the long run. In this regard, DCT distinguishes between ordinary and dynamic capabilities (Winter, 2003). Ordinary capabilities provide firms with considerable success in the present and near future. Although such ordinary capabilities are fundamental in performing organizational tasks on a daily basis, they do not guarantee a sustainable competitive advantage. In contrast, dynamic capabilities enable organizations to realign, reconfigure and renew ordinary capabilities that continuously support the ability to evolve through innovation and change. According to Teece (2014, p. 332), the purpose of dynamic capabilities is the "[...] (1) identification, development, co-development, and assessment of technological opportunities in relationship to customer needs (sensing); (2) mobilization of resources to address needs and opportunities and to capture value from doing so (seizing); and (3) continued renewal (transforming)." Maturity models are tools that contribute to these purposes.

The first manifestations of maturity models date back to the 1970s and are rooted in software engineering (Nolan, 1973; van Looy et al., 2013). Since then, the concept of maturity has evolved into an important tool in business practice. The concept of maturity can be used for descriptive, prescriptive and/or comparative purposes (Röglinger et al., 2012). It serves a descriptive purpose if applied for as-is assessments, a prescriptive purpose if used to establish a desirable path of development and a comparative purpose if used for internal or external benchmarking. Thus, maturity models are adequate tools for:

- documenting the status quo;
- developing a corporate vision for process excellence and providing guidance on that development path; and
- comparing capabilities between business units and organizations.

Because of the broad range of potential applications, maturity models have gained popularity both in management and science. Over the past decade, the number of scientific contributions has increased considerably (Wendler, 2012). Recently, Tarhan et al. (2016) performed a comprehensive systematic literature review. This paper does not intend to replicate the efforts of these researchers; rather, it complements this previous review with a detailed search and analysis of Industry 4.0/SCM 4.0 maturity models.

Tarhan et al. (2016) considered studies that were published between 1990 and 2014 in academic journals, conference proceedings and books. Their review is conducted in a general "all-inclusive manner" with no specific focus on a certain domain or aspect of business process management. Based on their search of digital libraries, they initially retrieved 2,899 references, with 61 of those considered relevant for further analysis. They report that most previous publications establish a maturity model, show the application of a model or compare different models. A key finding is the lack of empirical works on the development of maturity models. In addition, Tarhan et al. (2016) call for more prescriptive rather than descriptive models. This call has also been made by other authors (Isoherranen et al., 2015; van Looy et al., 2013). Descriptive models provide little guidance for the specific actions necessary to make it to the next maturity level. Tarhan et al. (2016) argued that a major prerequisite for the fulfillment of its prescriptive purpose is extensive documentation that lays out specific process areas, goals, best practices and achievement measures. Furthermore, these authors also emphasize that extensive models might deter decision makers because the models demand greater efforts for adoption.

Because the review process ended in October 2014, none of the 61 analyzed references considered the recent Industry 4.0 developments. Therefore, this paper aims to complement the previous review with the inclusion of more recent publications. The literature search was performed in common digital libraries such as EBSCOhost, Emerald Insight, ScienceDirect, Wiley and Google Scholar. The search terms covered "Industry 4.0," "Industrial Internet," "I 4.0," "Internet of Things," "IoT," "Cyber-Physical Systems" and "CPS" in combination with "maturity model" and "capability model." To ensure academic rigor, only publications from peer-reviewed journals and conference proceedings were considered. First, the abstracts of all identified references were analyzed with regard to their relevance. A publication was considered relevant if it presented a full model that included maturity stages and dimensions. The digital library research was complemented by the backtracking of footnotes and the search for citations of the identified relevant articles. Ultimately, ten studies were chosen for further analysis.

A comparison of the models reveals three publication streams (Table I.1). The first group of authors concentrates on IT architecture and/or capabilities, specifically with regard to the IoT (Jæger & Halse, 2017; Katsma et al., 2011; Weber et al., 2017). The second group that consists of only one contribution focuses specifically on CPS. The third group pursues a broader perspective (Westermann et al., 2016). The authors align their models to the Industry 4.0 phenomenon and acknowledge that digitization radically affects current business models in a unique and unprecedented way – especially the models of manufacturing companies (de Carolis et al., 2017; Ganzarain & Errasti, 2016; Gökalp et al., 2017; Klötzer & Pflaum, 2017; Leyh et al., 2016; Schumacher et al., 2016). The third group of maturity models is also the largest and raises the most interest among researchers, which is not surprising because Industry 4.0 conceptually integrates the IoT and CPS perspectives and represents the current state of the art.

Model	Focus	Stages/dimensions	Supported SCOR top-level processes (plan, source, make, deliver, return, enable)	Model documentation (attributes/characteristics for each maturity stage and dimension)
Katsma et al. (2011)	IT architecture /capabilities /IoT	4/4	Enable	Full documentation
Leyh et al. (2016)	Industry 4.0	5/4	Plan, enable	Full documentation
Ganzarain and Errasti (2016)	Industry 4.0	5/3	Plan, make, enable	Partial documentation
Schumacher et al. (2016)	Industry 4.0	5/9	Enable	Missing documentation
Westermann et al. (2016)	CPS	Layer 1: 5/1 Layer 2: 4-5/15	Enable	Partial documentation
Gökalp et al. (2017)	Industry 4.0	6/5	Enable	Missing documentation
Klötzer and Pflaum (2017)	Industry 4.0	5/18	Make, enable	Full documentation
Weber et al. (2017)	IT architecture /capabilities /IoT	5/1	Enable	Missing documentation
de Carolis et al. (2017)	Industry 4.0	5/4	Make, enable	Missing documentation
Jæger and Halse (2017)	IT architecture /capabilities /IoT	8/1	Enable	Missing documentation

Table I.1. Comparison of the proposed Industry 4.0 maturity models

To classify the maturity models in terms of content, the Supply Chain Operations Reference (SCOR) framework is used. SCOR was first presented in 1996 and has been constantly updated by the endorsing Supply Chain Council and now the American Production and Inventory Control Society. The most recent version is from 2017. The SCOR framework follows a hierarchical three-level structure that builds on the assumption that every supply chain can be described by using a set of predefined processes. The top level contains six basic process types that can be further subdivided into more detailed process categories and process elements (SCOR, 2017).

(1) Plan: The process balances resources with market requirements. It includes the gathering of requirements, the collection of data from available resources, the balancing of requirements and resources to determine planned capabilities, the identification of gaps in demand or resources and the planning of actions that correct these gaps. The process plays a superordinate strategic role.
(2) Source: The process includes all procurement activities concerning the ordering and receipt of goods and services from suppliers. It involves issuing purchase orders, scheduling deliveries and receiving, validating and storing goods.
(3) Make: The process describes all activities associated with the transformation of materials or the performance of services, which includes assembly, chemical processing, maintenance, repair, overhaul, recycling, refurbishment and remanufacturing.
(4) Deliver: The process includes all activities associated with the fulfillment of customer orders and consists of receiving, picking, packing, shipping and invoicing customer orders.
(5) Return: The process considers reverse flows of materials and goods and includes organizing the return shipment and deciding on the disposition option.

(6) Enable: The process establishes the fundamental requirements that are necessary for value creation within the supply chain and includes resource management, data management, facilities management, contract management, supply chain network management, compliance and risk management and performance management.

By applying this classification scheme to the ten models mentioned above, we conclude that several approaches support the plan, make and enable processes. However, a research gap is observed in the sourcing, delivery and return processes. To fully benefit from the Industry 4.0 concept, all value-adding processes must be considered via a holistic, integrated approach, which is particularly true because McCormack et al. (2008) found that the thus far neglected maturity of the delivery process has a greater impact on business performance than other SCOR processes.

Finally, the documentation of the previous models is mostly unsatisfactory, which seems to be a general problem with maturity models (Albliwi et al., 2014). From our point of view, none of the models can be fully applied using the given published information. Some do not even provide a full description of the maturity stages (Schumacher et al., 2016). Other models provide at least partial information and briefly describe the characteristics for each maturity stage and dimension (Klötzer & Pflaum, 2017; Westermann et al., 2016).

To summarize, the review shows that there is a lack of state-of-the-art Industry 4.0 maturity models with a comprehensive documentation that focus on the sourcing, delivery and return processes. Based on that, a model for the delivery process is developed in the following paragraph. The overall goal is to complement previous publications that focus on the manufacturing process. This model will allow decision makers to document the status quo, develop a vision for and provide guidance toward process excellence and compare capabilities between business units and organizations in outbound logistics as an important value-adding process (Rutner & Langley, 2000).

I.3 Development of the Industry 4.0 Maturity Model for Delivery Processes

Methodologically, this study is grounded in design science research (DSR). According to van Aken (2005, p. 22):

> DSR [.. .] is solution-oriented, using the results of description-oriented research from supporting (explanatory) disciplines as well as from its own efforts, but the ultimate objective of academic research in these disciplines is to produce knowledge that can be used in designing solutions to field problems.

We believe that the current Industry 4.0 development is a pertinent field problem that requires new capabilities to remain competitive; therefore, we consider DSR to represent an appropriate foundation. DSR focuses on the development and application of artifacts. In general, artifacts can be any type of construct, model or method (Hevner et al., 2004). In this paper, the artifact is the Industry 4.0 maturity model for the delivery processes in supply chains. According to Österle et al. (2010), a typical DSR project consists of four phases: analysis, design, evaluation and diffusion. This paper focuses on the design and evaluation steps by thoroughly describing the model's development and evaluation. Hevner et al. (2004) presented seven guidelines for DSR and highlight the importance of applying rigorous methods in the construction and evaluation of artifacts. Therefore, we build on the often-cited generic six phases of maturity model development presented by de Bruin et al. (2005) as described in the next paragraph.

I.3.1 Design Principles: Model Development Methodology

In their seminal work, de Bruin et al. (2005) presented six relevant phases: scope, design, populate, test, deploy and maintain. This study concentrates on the first five phases, which are further explained in the following sections because the sixth phase would require a longitudinal study.

I.3.1.1 Scope. The first phase defines the scope of the model, which can be either general or domain-specific. General models can be applied to different domains (e.g. quality management), whereas domain-specific models are coupled to a certain field of application (e.g. software development). Moreover, stakeholders that can assist in model development or benefit from the application of the model must be identified. These stakeholders may be from academia, industry, government or a combination.

I.3.1.2 Design. The second phase determines the architecture of the model based on five sub-criteria: audience, method of application, driver of application, respondents and application. It is important to define the target audience to meet their needs. This is especially relevant for the level of detail because a trade-off is observed between accuracy and simplicity.

With regard to the structural elements of a maturity model, de Bruin et al. (2005, p. 4) note that "[...] the number of stages may vary from model to model, but what is important is that the final stages are distinct and well-defined, and that there is a logical progression through stages." They also stress the need to provide "[...] a summary of the major requirements and measures of the stages, especially those aspects that are new to the stage and not included as elements of lower stages" (de Bruin et al., 2005, p. 4). These stages are applied to the model's dimensions. The inclusion of several dimensions allows for the modeling of complex domains. Each dimension may represent a different maturity stage, which facilitates detailed analyses and the identification of specific opportunities to make improvements.

I.3.1.3 Populate. The third phase broaches the issue of the specific content of the model by defining model components and subcomponents. A component denotes what needs to be measured. According to de Bruin et al. (2005), components can be defined by a review of the literature or the use of empirical approaches such as stakeholder interviews, surveys, focus groups and case studies.

I.3.1.4 Test. The fourth phase tests the validity and reliability of the model to strengthen the populated model's relevance and rigor. The model's validity guarantees that the model measures what it intends to measure, whereas reliability refers to whether the results are exact and repeatable. De Bruin et al. (2005) suggested several methods to ensure the model's validity and reliability, such as case studies, surveys, and literature reviews. They conclude that "[...] the manner in which testing is undertaken can vary between models [...]" (de Bruin et al., 2005, p. 9).

I.3.1.5 Deploy. The fifth phase combines the model's distribution within business practice for the purpose of determining its generalizability. De Bruin et al. (2005) proposed a two-step procedure to ensure the general acceptance of the model: applying the model to one of the involved stakeholders and applying the model to organizations that did not participate in the model's development and testing.

I.3.2 Model Development: Scope, Design, Populate and Test

The framework of de Bruin et al. (2005) serves as the methodological foundation for further procedures. The first four steps (scope, design, populate, and test) that represent the development in a narrower sense will be described in detail. To highlight the focus on the delivery process in conjunction with Industry 4.0, the model is named the Delivery Process Maturity Model (DPMM) 4.0.

I.3.2.1 Maturity model scope. The model's scope is designed for manufacturing firms and is thus domain-specific. These firms can be distinguished based on their production strategy. Possible strategies are make-to-stock, make-to-order, and engineer-to-order. Because most organizations either follow a make-to-stock or make-to-order approach, the model focuses on these two. Moreover, two types of stakeholders are considered relevant for model development: academia and industry. Therefore, the development process builds on available publications and original empirical work to adequately represent the practitioners.

I.3.2.2 Maturity model design. The targeted audience is internal executives and management (because they are responsible for developing and maintaining Industry 4.0 capabilities) as well as external auditors and consultants (because they are often engaged in guiding organizational change). The major drivers of the model's application are market dynamics that force organizations to rethink their business models. The respondents are management executives and mid-level staff, as they possess the expertise to assess their current Industry 4.0 capabilities. The model can be applied to multiple entities (e.g. production sites) in multiple regions. DPMM 4.0 can be used on an self- or guided assessment basis. After clarifying why and how the model is applied, the stages and dimensions must be defined. For this step, we refer to previous Industry 4.0 and maturity model literature.

I.3.2.2.1 Maturity stages of DPMM 4.0. Maturity stages represent a certain level of maturity and enable the improvement of the selected domain in a targeted way (Fraser et al., 2002). Each stage requires an appropriate denotation and a general description. Despite being a relatively new research domain, the literature review found six maturity models that have already been published (de Carolis et al., 2017; Ganzarain & Errasti, 2016; Gökalp et al., 2017; Klötzer & Pflaum, 2017; Leyh et al., 2016; Schumacher et al., 2016). Consequently, information is available on the criteria for maturity and the methods of measuring maturity. Beyond the six identified Industry 4.0 maturity models, the contribution of Leyh et al. (2016) stands out. Compared with the other models, the System Integration Maturity Model Industry 4.0 (SIMMI 4.0) is based on two of the most established and widely employed maturity models: Capability Maturity Model Integration (CMMI) and the Service-Oriented Architecture Maturity Model (SOAMM). Moreover, SIMMI 4.0 stands out based on its comprehensive documentation. Consequently, the maturity stages of DPMM 4.0 are based on those of SIMMI 4.0 and adopted for the delivery process. Table I.2 summarizes the maturity stages and provides a detailed description.

Maturity stage	Description
Stage 1 – Basic digitization	The organization has not addressed Industry 4.0; the delivery process is not digitized; the continuous availability of data is not ensured; the available enterprise IT-system supports only its field of application. Consequently, several data islands can be found along the process.
Stage 2 – Cross-department digitization	The organization begins to address Industry 4.0 issues within the departments that contribute to the delivery process (logistics, warehousing, and customer service); the data are fully integrated in a single enterprise system; information can be exchanged among different departments. However, data exchange is not automatized. The organization starts to follow Service Oriented Architecture (SOA) principles and enables direct connection between information systems.
Stage 3 – Horizontal and vertical digitization	Within organizational borders, the delivery process is digitized; Industry 4.0 requirements have been implemented within the organization; data flows are automated in which information can be forwarded to the next or to previous process steps; data exchange follows cloud principles; services are available company-wide and employees can access information everywhere through mobile devices; objects (e.g., products, shipments) actively provide stored information as soon as a reader comes into the range of the objects.
Stage 4 – Full digitization	Digitization of the delivery process is achieved beyond corporate borders; Industry 4.0 principles are actively followed by all business partners; the digitized organization collaborates with customers and external service providers to develop end-to-end solutions; available order and delivery information is automatically shared with customers and service providers. The service-oriented and cloud-based platform is available supply chain-wide; appropriate encryption and authentication techniques are in place to ensure safe data access.

Maturity stage	Description
Stage 5 – Optimized full digitization	Full digitization of the internal and cross-corporate delivery process along with strong collaboration with customers and external service providers lays the foundation for developing self-adjustment and self-optimization capabilities that act autonomously. The available data allow for the real-time simulation of the delivery process, which can be used in collaborative diagnostics and decision making. Artificial intelligence and self-learning abilities are integrated in the information systems.

Table I.2. DPMM 4.0 maturity stages adapted from Leyh et al. (2016)

I.3.2.2.2 Model dimensions of DPMM 4.0. The model's dimensions add specific content to the previously defined maturity stages (Fraser et al., 2002). Each dimension consists of elements or activities that allow a detailed understanding of the described phenomenon (Fraser et al., 2002). Methodologically, an appropriate denotation and a general definition of each element are required (de Bruin et al., 2005).

The frequently used SCOR framework subdivides the top-level Delivery process (sD) into four categories based on the respective production strategy: deliver make-to-stock (sD1), deliver make-to-order (sD2), deliver engineer-to-order (sD3) and deliver retail product (sD4). Because this maturity model is designed for manufacturers with make-to-stock or make-to-order production strategies, only sD1 and sD2 are taken into further consideration. A comparison between these two categories reveals considerable consistency, with both including 15 elements and exhibiting only two minor differences. First, sD2.2 allows for the customer-specific configuration of a product based on the standardized available parts or other offered options which is not included in sD2.1. Second, the title of sD1.11 (load vehicle and generate shipping docs) differs from that of sD2.11 (load product and generate shipping docs). However, this deviation is only semantic and can be neglected with regard to model development because the definitions of the given elements match. Moreover, several of the activities serve a similar purpose, thereby providing the basis for three process groups: order processing, warehousing and shipping. Table I.3 provides the relevant process elements and their assignment to the process groups. For the detailed element descriptions, refer to the SCOR (2017) framework.

ID (sD1/sD2) – SCOR process element	**Process element group**
sD1.1/sD2.1 – Process inquiry and quote	Order processing
sD1.2/sD2.2 – Receive (,configure), enter and validate order	Order processing
sD1.3/sD2.3 – Reserve inventory and determine delivery date	Order processing
sD1.4/sD2.4 – Consolidate orders	Order processing
sD1.5/sD2.5 – Build loads	Shipping
sD1.6/sD2.6 – Route shipments	Shipping
sD1.7/sD2.7 – Select carriers and rate shipments	Shipping
sD1.8/sD2.8 – Receive product from source or make	Warehousing
sD1.9/sD2.9 – Pick product	Warehousing
sD1.10/sD2.10 – Pack product	Warehousing
sD1.11/sD2.11 – Load vehicle/product and generate shipping docs	Shipping
sD1.12/sD2.12 – Ship product	Shipping
sD1.13/sD2.13 – Receive and verify product by customer	Shipping
sD1.14/sD2.14 – Install product	Shipping
sD1.15/sD2.15 – Invoice	Order processing

Table I.3. Overview of the relevant process elements

To summarize, DPMM 4.0 consists of five maturity stages (basic digitization, cross-department digitization, horizontal and vertical digitization, full digitization and optimized full digitization) that are applied to three dimensions (order processing, warehousing and shipping). Each dimension has three to seven elements. The high level of detail enables rich analyses of the maturity results and improves the ability to derive a supply chain-specific development path. After conceptually determining the design, the subsequent paragraph focuses on the model's content.

I.3.2.3 Maturity model population. Several publications present successful Industry 4.0 approaches that are summarized and described in Table I.4. The identified approaches are not mutually exclusive and include various overlaps. However, these similarities are not considered critical because this stage of the model's development is focused on comprehensiveness rather than on the segregation of concepts.

Industry 4.0 approach	**Description**	**References**
Integrated database	The company uses a single consistent database that integrates disparate sources of data from different departments.	Zhou et al. (2015, p. 2148), Shrouf et al. (2014, p. 698)
Integrated interfaces	The organization provides shared and integrated interfaces to avoid media discontinuities; this refers to interfaces between organizations, human-machine-interfaces and user/product interfaces.	Zhou et al. (2015, p. 2148), Hermann et al. (2016, p. 3932), Shrouf et al. (2014, p. 698), Han and Chi (2016, p. 109), Butzer et al. (2016, p. 5), Biahmou et al. (2016, p. 673)
Consistent data/ information flow	An end-to-end data/information flow is built from multiple sources to enable real-time analytics.	Gilchrist (2016, p. 206 and 208), Varghese and Tandur (2014, p. 634), Kagermann (2015, p. 30)
Mobile devices	Employees can access, edit, and add information everywhere through mobile devices that use cloud services.	Varghese and Tandur (2014, p. 634), Zhou et al. (2015, p. 2149), Shrouf et al. (2014, p. 698)

Industry 4.0 approach	Description	References
Digital mapping	Data on the physical reality are compiled and formatted into a virtual image to create a digital twin. The digital twins create simulation models for the purpose of monitoring, diagnostics and prognostics.	Gilchrist (2016, p. 207), Zhou et al. (2015, p. 2148), Hermann et al. (2016, p. 3929)
Automated monitoring	Full tracking and traceability of all processes and associated goods with seamless real-time feedback regarding their status is provided.	Gilchrist (2016, p. 208), Kagermann (2015, p. 30)
Machine learning	Systems are provided with algorithms that can learn from existing data without being explicitly programmed.	Shrouf et al. (2014, p. 699), Hermann et al. (2016, p. 3934), Han and Chi (2016, p. 111)
Self-optimization	Providing decentralized systems with the ability to react autonomously to changing external conditions and providing optimal solutions by adapting objectives as well as the resulting behavior.	Shrouf et al. (2014, p. 699), Kagermann (2015, p. 30), Gölzer et al. (2015, p. 2), Butzer et al. (2016, p. 2)
Partner integration	Customers, suppliers, and other external partners are integrated with the ultimate goal of creating distinct industrial digital ecosystems.	Kiel et al. (2016, p. 689), Biahmou et al. (2016, p. 673), Arnold et al. (2016, p. 1640015-6)

Table I.4. Overview of Industry 4.0 approaches

To verify the relevance and test the comprehensiveness of the identified approaches, a complementary empirical study is conducted. With the support of a stakeholder, a leading Industry 4.0 corporation from the manufacturing industry that wishes to remain anonymous, and additional searches on professional social networks (LinkedIn, Xing), 207 experts were identified and invited to participate in an online survey. The questionnaire consisted of three parts. The first part collected data concerning the respondents' Industry 4.0 experience. The second part aimed to ensure the maturity model's exhaustiveness. Therefore, participants were asked to rate the relevance of the identified Industry 4.0 approaches for each of the DPMM 4.0 dimensions (order processing, warehousing and shipping) on a four-tiered Likert scale (not relevant, marginally relevant, fairly relevant and highly relevant). The respondents were allowed to choose "not sure" in the case of missing expertise. Moreover, they were invited to name and describe additional Industry 4.0 approaches that have not been queried, but appear to be relevant in the respective dimension. Finally, the third part contained general demographic questions (e.g. age and sex). Before going live, five experts that represented both academia and industry pre-tested the questionnaire and their suggestions regarding question sequence and wording were considered in the final version of the questionnaire.

The field phase occurred in late May and June 2017. In total, 43 experts finished the survey, which equals a response rate of 20.6 per cent. The participants indicated that they were from upper organizational hierarchy levels with the majority from top management (25 per cent) or middle management (37 per cent). Five experts were from academia to complement the industry-dominated sample. Most of the participants (86 per cent) worked for large corporations with over 250 employees. On average, the respondents were 40.7 years old. Because top-level jobs are primarily held by men (Dezso et al., 2013), the participants were also pre-dominantly male (86 per cent). Despite the novelty of the concept, over half of the respondents (58 per cent) indicated that they had been working on Industry 4.0 approaches for more than two years. Therefore, we are confident that the sample reflects the necessary expertise to contribute to the population of the model.

After the field phase, the collected data were analyzed with regard to the response behavior and no anomalies were found. Overall, all of the cited Industry 4.0 approaches seem relevant for the delivery process with averages varying from 2.83 to 3.81 (Table I.5). A one-way ANOVA found that the following elements presented significant differences between the three queried process groups: integrated database, integrated interfaces, digital mapping and partner integration.

Industry 4.0 approach	**Order processing** Avg. (SD)	**Warehousing** Avg. (SD)	**Shipping** Avg. (SD)	**ANOVA results** $F(df_{between\ groups}, df_{within\ groups})$= F ratio, Sig. value
Integrated database	3.79 (0.41)	3.33 (0.72)	3.69 (0.52)	F(2, 124)=7.69, p=0.001
Integrated interfaces	3.81 (0.39)	3.33 (0.78)	3.76 (0.43)	F(2, 125)=9.74, p<0.001
Consistent data/information flow	3.60 (0.73)	3.49 (0.71)	3.72 (0.55)	F(2, 123)=1.28, p=0.282
Mobile devices	3.15 (0.73)	3.20 (0.79)	3.48 (0.71)	F(2, 120)=2.37, p=0.098
Digital mapping	3.33 (0.84)	3.00 (0.86)	3.44 (0.83)	F(2, 125)=3.16, p=0.046
Automated monitoring	3.43 (0.80)	3.36 (0.69)	3.62 (0.58)	F(2, 123)=1.58, p=0.210
Machine learning	3.21 (0.78)	3.02 (0.81)	3.30 (0.74)	F(2, 124)=1.42, p=0.246
Self-optimization	3.23 (0.84)	3.00 (0.91)	3.24 (0.73)	F(2, 117)=1.10, p=0.338
Partner integration	3.26 (0.69)	2.83 (0.81)	3.49 (0.68)	F(2, 116)=8.66, p<0.001

Table I.5. Results of the survey concerning Industry 4.0 approaches

To assess the groups that differ from each other post hoc Tukey tests were performed. The results show that an integrated database is less important for warehousing than it is for order processing (p = 0.001, -0.46, 95%-CI [-0.75, -0.17]) and shipping (p = 0.012, -0.36, 95%-CI[-0.65, -0.07]) processes. Moreover, integrated interfaces are significantly less important for warehousing than for order processing (p < 0.001, -0.49, 95%-CI[-0.78,

-0.20]) and shipping (p < 0.001, -0.44, 95%-CI[-0.73, -0.15]). In the case of digital mapping a significant difference between warehousing and shipping (p = 0.044, -0.44, 95%-CI[-0.87, -0.01]) was observed. Similar results were observed for partner integration, which is significantly less relevant for warehousing than for order processing (p = 0.024, -0.44, 95%-CI[-0.83, -0.05]) and shipping (p < 0.001, -0.66, 95%-CI [-1.05, -0.28]) processes.

Overall, the results show that while all queried Industry 4.0 approaches seem to be highly relevant for order processing and shipping, the approaches are not as relevant for warehousing. In fact, the collected data imply that digitization in warehousing is generally less relevant, which can be attributed to the changing role of warehousing. Industry 4.0 supply chains require fewer inventories because of shorter cycle/lead times, better planning and more sophisticated forecasting capabilities. The mantra is: “less storage, more flow” (Harrington, 2004). Although the number of warehouses might decrease in the future, they will most likely not disappear as a relic of outdated business models. Inventory will still provide flexibility and act as the facilitator of last resort between supply and demand. The highest potential for digitization will likely occur in the support of accurate warehousing/distribution functions and the provision of tracking and traceability (Harrington, 2004), which require a consistent data flow and automated process monitoring, the two highest-rated approaches.

The few answers provided to the open questions indicate the comprehensiveness of the surveyed Industry 4.0 approaches. Several participants noted a specific need to consider simulations for warehousing and shipping processes and the utilization of autonomous vehicles, robotics and RFID containers for warehousing processes.

When processing the gathered information, a top-down approach was chosen. The previous Industry 4.0 literature in combination with survey results was used to develop an Industry 4.0 vision for the delivery process. This vision populates the model for each DPMM 4.0 model element on the highest maturity stage: “Stage 5 – Optimized full digitization”. Subsequently, the content of the remaining four stages was gradually derived following three guidelines. Starting from the Industry 4.0 vision, each lower maturity stage was characterized by:

- more human interventions;
- lower inter- and intra-organizational integration; and
- less automatized data and information flows.

I.3.2.4 Maturity model testing. After populating the model, it had to be tested for validity and reliability (de Bruin et al., 2005). For this development stage, the paper refers to Becker et al. (1995), who suggested principles for good model development, and Mettler (2010), who presented criteria to characterize the quality of a maturity model. The criteria taken into account included comprehensibility, comprehensiveness, relevance, consistency, systematic structure, detailedness, conceptual reliability and applicability. These criteria were applied to the Industry 4.0 vision for the delivery process, that is, Stage 5 of the DPMM 4.0. Table I.6 provides a detailed description.

To assess the model, another online survey was initiated that consisted of two parts. First, experts were asked to assess the eight quality criteria for the three dimensions (order processing, warehousing and shipping). A four-tiered Likert scale (strongly disagree, fairly disagree, fairly agree and strongly agree) was used for this purpose. The participants were advised to select “not sure” if they lacked expertise. Additionally, open questions provided participants the opportunity to name important issues that have not been considered in the presented Industry 4.0 vision. Second, the respondents were asked for demographic information. Before data collection, the questionnaire was pre-tested by five experts from both industry and academia in terms of wording and design.

Quality criteria	Description
Comprehensibility	The Industry 4.0 vision is easy to understand.
Comprehensiveness	The Industry 4.0 vision considers all relevant parameters.
Relevance	The Industry 4.0 vision contains only elements that are important and consistent with the purpose of the maturity model.
Consistency	The Industry 4.0 vision is inherently conclusive.
Systematic structure	The Industry 4.0 vision displays a logical composition.
Detailedness	The Industry 4.0 vision is ideal for a model with regard to the level of detail.
Conceptual reliability	The Industry 4.0 vision fulfills the conception of Industry 4.0.
Applicability	The Industry 4.0 vision supports the implementation of Industry 4.0.

Table I.6. Quality criteria for evaluating the maturity model

The 207 identified Industry 4.0 experts were invited to participate in July 2017. In total, 37 participants completed the survey, which equals a response rate of 19.8 per cent. Almost half of the respondents (43 per cent) had already shared their expertise during the first survey. Again, most of the participants indicated that they were from upper organizational hierarchy levels that included top (43 per cent) or middle (21 per cent) management. The majority of the respondents (78 per cent) worked for large corporations with over 250 employees. The only major differences between the first and the second survey were in terms of age and sex: the respondents were noticeably older (49.1 years old), and the proportion of men was even higher (94.6 per cent) in the second survey. Anomalies concerning response behavior were not found.

For all the queried quality criteria, the averages showed satisfactory values between 2.97 and 3.73 (Table I.7). A one-way ANOVA showed only one significant difference between the three process groups: relevance. The post hoc Tukey test indicated that the populated Industry 4.0 vision is considered less relevant for order processing than for shipping processes (p = 0.014, -0.44, 95 %-CI[-0.81, -0.08]). This finding in conjunction with the comparatively low value for detailedness led to a critical reflection of the respective model component.

Quality criteria	**Order processing** Avg. (SD)	**Warehousing** Avg. (SD)	**Shipping** Avg. (SD)	**ANOVA results** $F(df_{between\ groups}, df_{within\ groups})$ = F ratio, Sig. value
Comprehensibility	3.62 (0.49)	3.63 (0.49)	3.51 (0.51)	F(2, 106)=0.62, p=0.541
Comprehensiveness	3.12 (0.65)	3.24 (0.55)	3.27 (0.52)	F(2, 97)=0.62, p=0.540
Relevance	2.97 (0.62)	3.30 (0.64)	3.41 (0.66)	F(2, 99)=4.48, p=0.014
Consistency	3.50 (0.56)	3.50 (0.56)	3.56 (0.50)	F(2, 105)=0.13, p=0.882
Systematic structure	3.59 (0.55)	3.53 (0.56)	3.73 (0.45)	F(2, 105)=1.37, p=0.259
Detailedness	3.07 (0.74)	3.34 (0.70)	3.39 (0.61)	F(2, 92)=2.06, p=0.134
Conceptual reliability	3.26 (0.66)	3.40 (0.55)	3.42 (0.60)	F(2, 103)=0.74, p=0.481
Applicability	3.31 (0.71)	3.35 (0.54)	3.42 (0.55)	F(2, 103)=0.30, p=0.740

Table I.7. Survey results regarding quality criteria

At this point, we are still confident that the model reflects the relevant Industry 4.0 approaches and that an appropriate level of detail was applied. However, special attention will be paid to this specific model part during future implementations, and if necessary, changes will be made. The few answers to the open questions indicated the comprehensiveness of the surveyed Industry 4.0 vision. Several participants suggested the inclusion of the following aspects: suppliers' delivery capacity, product surveillance during storage, considering customer requests despite the Frozen Zone and decision-making regarding the replacement of an initial product, the provision of spare parts or an appointment with service technicians when critical product conditions are reached.

I.3.3 Presentation of the Final Maturity Model and Initial Deployment

Figure I.1 provides an overview of the final model. The full version that includes the detailed description at the element level is available as an Appendix. Compared with other approaches, DPMM 4.0 recognizes that every organization has a unique structure. Therefore, companies that use the model must examine their delivery process first to determine the relevant sD1 or sD2 SCOR process elements. Only these elements will be considered during the maturity assessment procedure.

The assessment begins with general information about the participating company (the number of employees, annual turnover and industry) to prepare potential internal or external benchmarking and to identify the production strategy in place. The participants are required to review the SCOR process elements for $i = \{1,2,3\}$ model dimensions, including order processing DIM_1 = {sD1.1/sD2.1, sD1.2/sD2.2, sD1.3/sD2.3, sD1.4/sD2.4, sD1.15/sD2.15}, warehousing DIM_2 = {sD1.8/sD2.8, sD1.9/sD2.9, sD1.10/sD2.10} and shipping DIM_3 = {sD1.5/sD2.5, sD1.6/sD2.6, sD1.7/sD2.7, sD1.11/sD2.11, sD1.12/sD2.12, sD1.13/sD2.13, sD1.14/sD2.14} and select the relevant ones, that is, $RDIM1 \subseteq DIM1$, $RDIM2 \subseteq DIM2$, and $RDIM3 \subseteq DIM3$. If the organization already uses the SCOR framework, then it may rely on available flow charts for this task.

	Order processing	Warehousing	Shipping
Stage 1 – Basic digitization	Order processing is not digitized; Manual exchange of data/information between order processing and other departments; Enterprise system supports only order processing (department-specific)	Warehousing is not digitized; Manual exchange of data/ information between ware-housing and other departments; Enterprise system supports only warehousing (department-specific)	Shipping is not digitized; Manual exchange of data/information between shipping and other departments; Enterprise system supports only shipping process (department-specific)
Stage 2 – Cross-department digitization	Order processing is digitally supported; Electronic exchange of data/information between order processing and other depart-ments; Department-wide inte-gration of order processing into enterprise systems	Warehousing is digitally supported; Electronic exchange of data/ information between ware-housing and other departments; Department-wide integration of warehousing into enterprise systems	Shipping is digitally supported; Electronic exchange of data/ information between shipping and other departments; Department-wide integration of shipping into enterprise systems
Stage 3 – Horizontal and vertical digitization	Order processing is continuously digitally supported; Automated flow of data/information within the company (e.g., order confirmation); Shared, integrated interfaces (e.g., receipt of orders); Recourse to company-specific data for order processing (e.g., determination of delivery date); Company-wide integration of order processing into cloud-based IoT operating system; Access to order processing information through mobile device	Warehousing is continuously digitally supported; Automated flow of data/information within the company (e.g., planning picking waves); Recourse to company-specific data for warehousing (e.g., product storage); Company-wide integration of warehousing into cloud-based IoT operating system; Access to warehousing information through mobile device	Shipping is continuously digitally supported; Automated flow of data/information within the company (e.g., planning transportation mode); Recourse to company-specific data for shipping process (e.g., delivery date); Automated monitoring for full traceability; Company-wide integration of shipping into cloud-based IoT operating system; Access to shipping information through mobile device
Stage 4 – Full digitization	Automated real-time order processing is continuously digitally supported; Automated real-time flow of data/information; Recourse to customer-specific data as well as business partner data for comprehensive order processing (e.g., carriers' capa-city); Supply chain-wide inte-gration of order processing into cloud-based IoT operating system	Automated real-time ware-housing is continuously digitally supported; Automated real-time flow of data/information; Recourse to customer-specific data for comprehensive ware-housing (e.g., customized pack-aging); Supply chain-wide integration of warehousing into cloud-based IoT operating system	Automated real-time shipping is continuously digitally supported; Automated real-time flow of data/information; Recourse to customer-specific data as well as business partner data for comprehensive shipping (e.g., customer's preferred routes); Supply chain-wide integration of shipping into cloud-based IoT operating system
Stage 5 - Optimized full digitization	Automated real-time order processing is continuously digitally supported within the supply chain; Real-time simulation for decision making (e.g., order confirmation); Real-time optimization (e.g., determination of delivery date); Self-learning abilities from solved cases; Supply chain-wide integration of order processing into self-optimizing cloud-based IoT operating system	Automated real-time warehousing is continuously digitally supported within the supply chain; Real-time simulation for decision making (e.g., cost-effective packaging); Real-time optimization (e.g., routes of auto-nomously acting transportation system); Real-time self-adjust-ment to changing environment; Self-learning abilities from solved cases; Supply chain-wide integration of warehousing into self-optimizing cloud-based IoT operating system	Automated real-time shipping is continuously digitally supported within the supply chain; Real-time simulation for decision making (e.g., efficient grouping of orders); Real-time optimization (e.g., routes of autonomously acting transportation system); Real-time self-adjustment to changing environment; Self-learning abilities from solved cases; Supply chain-wide integration of shipping into self-optimizing cloud-based IoT operating system

Figure I.1. Overview of the DPMM 4.0

The chosen elements in dimension i are assigned to the consecutive index j(i)={1,...,J(i)}. For each element DPMM 4.0 provides k(j(i))={1,...,K(j(i))} statements that are evaluated on a four-tiered scale (0="not implemented", 1="partly implemented", 2="for the most part implemented" and 3="fully implemented"). The assessments $as_{i,j(i),k(j(i))}$ are converted to percentage scores for each model element (1), dimension (2), and the entire process (3) following these formulas:

- The potential element score $PES_{i,j(i)}$, the achieved element score $AES_{i,j(i)}$, and the relative element score $RES_{i,j(i)}$:

$$PES_{i,j(i)} = K\left(j(i)\right) \cdot 3 \qquad \forall\, i, j(i)$$

$$AES_{i,j(i)} = \sum_{k(j(i))=1}^{K(j(i))} as_{i,j(i),k(j(i))} \qquad \forall\, i, j(i)$$

$$RES_{i,j(i)} = \frac{AES_{i,j(i)}}{PES_{i,j(i)}} \cdot 100\,\% \qquad \forall\, i, j(i)$$

- The relative dimension score RDS_i:

$$RDS_i = \frac{\sum_{j(i)=1}^{J(i)} AES_{i,j(i)}}{\sum_{j(i)=1}^{J(i)} PES_{i,j(i)}} \cdot 100\,\% \qquad \forall\, i$$

- The total relative process score TRPS:

$$TRPS = \frac{\sum_{i=1}^{3} \sum_{j(i)=1}^{J(i)} AES_{i,j(i)}}{\sum_{i=1}^{3} \sum_{j(i)=1}^{J(i)} PES_{i,j(i)}} \cdot 100\,\%$$

Finally, the relative score is converted into a maturity stage. With the five stages describing a path towards excellence, the scale is evenly distributed. That is, the first stage corresponds to a score between 0 and 20 per cent, the second stage to a score between 20 and 40 per cent, the third stage to a score between 40 and 60 per cent, the fourth stage to a score between 60 and 80 per cent, and the fifth stage to a score between 80 and 100 per cent.

The cascading structure allows for a brief initial overview of the delivery process's maturity, which serves a descriptive purpose. For the prescriptive purpose, the process elements with the lowest scores must be identified since they present the greatest digitization deficits. Because those elements are a bottleneck to the entire process, these areas must be addressed first. A case-specific development path can be derived by reviewing the detailed description of the next maturity level and the respective assessment statements to determine the requirements for ascending the maturity ladder. However, applicants should not automatically strive for the highest level. Rather, critical reflection is required to determine whether a specific measure makes sense economically. Thus, a cost-benefit analysis must be performed, and whether the measures fit the organizational and supply chain-specific objectives must be determined.

The final DPMM 4.0 has been successfully deployed at a company that supported the development as a stakeholder. The management of the multinational firm was highly interested in a tool that complements their already used maturity model for manufacturing processes. DPMM 4.0 has been used to assess, benchmark and compare two sites with what finally led to the derivation of a roadmap toward excellence in the company's delivery processes. The corresponding detailed case study has been published in a separate article (Felch et al., 2018).

I.4 Summary, Limitations and Outlook

Our initial literature review shows that previous maturity models in the Industry 4.0 context have focused on the production processes in manufacturing firms. Nevertheless, the Industry 4.0 idea also influences the upstream and downstream stages of value creation in industrial companies. In the long run, the exclusive consideration of production processes will be insufficient when the involvement of other value creation stages (e.g. sourcing or logistics) is disregarded. Without the expansion of the Industry 4.0 idea to the entire industrial value chain, the capabilities of Industry 4.0 cannot be completely exploited, and the accruing competitive advantages cannot be deployed.

Against this background, this paper closes a research gap by providing a theoretically grounded, methodologically rigorous development of a maturity model for the delivery processes of manufacturing firms. The value of the presented model resides in the combination of scientific rigor, practical relevance, and direct applicability. Röglinger et al. (2012, p. 328) called for more "[...] elaborate support by means of ready-to-use and adaptable instruments for maturity assessment and improvement." DPMM 4.0 is both ready-to-use and adaptable. The tool is directly applicable because of its extensive documentation. Despite the limited space in peer-reviewed articles, this paper describes the model's scope, purpose of use, structure (maturity stages, dimensions and elements), target groups, potential assessment methods and the maturity score calculations. The adaptability is derived from the model's reference to the SCOR framework. Because SCOR is successfully and widely used in business practice, we believe that it is the ideal basis for process maturity models. Therefore, from a theoretical perspective, our approach might serve as the blueprint for maturity models of other value-adding processes that have also received limited consideration until now (e.g. the sourcing process). The modularized structure makes DPMM 4.0 generic as well as customizable.

With regard to business practice, this work provides detailed knowledge on how to digitize outbound logistics, which could become a critical bottleneck on the path toward a connected and smart supply chain. The developed model is a good starting point for practitioners who seek to ensure the competitiveness of their distribution processes in the digital age ahead. In short, DPMM 4.0 allows an organization to determine its current maturity level in each delivery sub-process, to compare its current maturity level with other sites, business units and/or companies, to develop a corporate vision for delivery logistics excellence, to identify potential improvement measures and to provide guidance on the development path.

There are also limitations to this study. First, maturity models have generally been subject to criticism (Albliwi et al., 2014) with certain authors arguing that these models oversimplify reality and that their fundamental stage hypothesis lacks an empirical foundation (Benbasat et al., 1984). However, several case studies have shown the benefits of maturity models (Isoherranen et al., 2015). These models have been successfully applied in business practice and represent a popular tool for developing operational excellence to strengthen corporate and supply chain competitiveness. Second, although the development process has been supported by both previous publications and empirical work, these expert opinions and judgments still contain a certain degree of subjectivity. Moreover, the model population and evaluation process was mostly based on experts from German industrial companies, which imposes a potential regional bias. Therefore, further research should consider a more international perspective.

Moreover, although the concept of Industry 4.0 may have reached a degree of maturity, it is still an evolving concept. Therefore, critical assessments are required to determine whether the highest maturity stage continues to reflect the current technological state-of-the-art. With the further emergence of digitization aspects, the model will have to be reviewed. In this regard, the model might benefit from its reference to the SCOR model, which is further developed on an ongoing basis. Relevant structural changes in the delivery process would be considered in the SCOR framework. Therefore, future versions should be compared with the current SCOR 12 and potential changes regarding the delivery process elements should trigger a subsequent revision of DPMM 4.0 elements. Additionally, the development of new delivery process technologies might necessitate additional assessment statements or further maturity levels for drastic changes.

Tarhan et al. (2016, p. 130) highlight that "[...] the attention in research has been at the development and release of models, while empirical works on the validation of these models are few and far between." Notwithstanding the successful application of the model at a multinational company from the electronics industry (Felch et al., 2018), this criticism also applies to this paper. The authors are currently working on providing further case studies that demonstrate the model's applicability. However, because additional empirical verifications are always warranted, future research should aim to further exemplify the generalizability of DPMM 4.0.

Despite these limitations, we are confident that our work is suitable for providing structured insights in the digitization of outbound logistics, an important value-adding activity in SCM. Herein, this study adds another piece to the puzzle for the purpose of supporting today's manufacturing firms and their supply chains in the development of tomorrow's digital equivalents.

I.5 Appendix. DPMM 4.0 – Model Documentation

Content

- Process inquiry and quote (sD1.1/sD2.1)
- Receive (, configure), enter and validate order (sD1.2/sD2.2)
- Reserve inventory and determine delivery date (sD1.3/sD2.3)
- Consolidate orders (sD1.4/sD2.4)
- Build loads (sD1.5/sD2.5)
- Route shipments (sD1.6/sD2.6)
- Select carriers and rate shipments (sD1.7/sD2.7)
- Receive product from source or make (sD1.8/sD2.8)
- Pick product (sD1.9/sD2.9)
- Pack product (sD1.10/sD2.10)
- Load vehicle/product and generate shipping docs (sD1.11/sD2.11)
- Ship product (sD1.12/sD2.12)
- Receive and verify product by customer (sD1.13/sD2.13)
- Install product (sD1.14/sD2.14)
- Invoice (sD1.15/sD2.15)

Process inquiry and quote (sD1.1/sD2.1)

"Receive and respond to general customer inquiries and requests for quotes." (SCOR, 2017, p. 2.5.6 and p. 2.5.26)

Stage 1 – Basic digitization

- Electronic receipt of customer inquiries and request for quotes via phone, fax or e-mail;
- Manual data entry in the company's order processing system;
- Manual procurement and analysis of relevant information (e.g. production and delivery data); and
- Manual response to customer inquiries and request for quotes via phone, fax or e-mail.

Stage 2 – Cross-department digitization

- Electronic receipt of customer inquiries and request for quotes via standardized interface;
- Manual verification of transmission, correction and addition of data;
- Electronic assembly of relevant information in a one-page format; and
- Electronic response to customer inquiries and request for quotes via standardized interface.

Stage 3 – Horizontal and vertical digitization

- Automatic receipt of customer inquiries and request for quotes via standardized interface;
- Guarantee of correct filling due to stored metadata;
- In cases of failure: color-marking of the respective fields, notification of the responsible parties and manual correction of data;
- Recourse to company-specific data (e.g. production and delivery data) when creating response;

- Automatic response to customer inquiries and request for quotes via standardized interface; and
- Access to order processing information through mobile devices.

Stage 4 – Full digitization

- Automated real-time receipt of customer inquiries and request for quotes;
- Recourse to customer-specific data if the business partner already exists in the system;
- Recourse to carrier data or experience; and
- Automated real-time response to customer inquiries and request for quotes.

Stage 5 – Optimized full digitization

- Real-time simulation for decision-making;
- Automated analysis of customer inquiries, request for quotes or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Receive (, configure), enter and validate order (sD1.2/sD2.2)

"Receive orders from the customer and enter them into a company's order processing system. Orders can be received through phone, fax, or electronic media. (Configure your product to the customer's specific needs, based on standard available parts or options.) Technically' examine orders to ensure an orderable configuration and provide accurate price. Check the customer's credit. Optionally accept payment." (SCOR, 2017, p. 2.5.7 and p. 2.5.27)

Stage 1 – Basic digitization

- Electronic receipt of customer order via phone, fax or e-mail;
- Manual data entry in the company's order processing system;
- Manual procurement and analysis of relevant information from various IT systems;
- Manual verification for orderable configuration and calculation of accurate price;
- Manual check of customers' credit;
- (Manual configuration of product to the customer's need or request based on standard available parts or other offered options);
- Electronic order confirmation via phone, fax or e-mail;
- Electronic transmission of order modifications via phone, fax or e-mail;
- Manual verification of modifications (e.g. feasibility analysis, availability check of material, capacity check);
- Manual revision of cost situation and calculation of price adjustments; and
- Electronic message to inform the customer about decision on approval or rejection.

Stage 2 – Cross-department digitization

- Electronic receipt of order via standardized interface;
- Manual verification of transmission, correction and addition of data;

- Electronic assembly of relevant data in one-page format;
- Electronically supported verification for orderable configuration and calculation of accurate price;
- Electronically supported check of customers' credit;
- (Electronically supported configuration of product to the customer's need or request based on standard available parts or other offered options);
- Electronic order confirmation via standardized interface;
- Electronic transmission of order modifications via standardized interface;
- Electronically supported verification of modifications (e.g. feasibility analysis, availability check of material, capacity check);
- Electronically supported revision of cost situation and calculation of price adjustments; and
- Automated message to inform the customer about decision on approval or rejection.

Stage 3 – Horizontal and vertical digitization

- Automatic transmission of order via standardized interface;
- Guarantee of correct filling due to stored metadata;
- In cases of failure: colored marking of the respective fields, notification of the responsible parties and manual correction of data;
- Automated procurement of missing data;
- Recourse to company-specific information (e.g. current and future production and delivery utilization, electronically stored flow charts) for analyzing order status;
- Automated verification for orderable configuration and calculation of accurate price;
- Automated check of customer's credit;
- (Automated configuration of product to the customer's need or request based on standard available parts or other offered options);
- Automated transmission of order confirmation via standardized interface;

- Automated transmission of order modifications via standardized interface;
- Automated identification and colored marking of modifications;
- Electronically supported verification of modifications (e.g. feasibility analysis, availability check of material, capacity check);
- Electronically supported revision of the cost situation and calculation of price adjustments;
- Automated message to inform the customer about decision about approval or rejection; and
- Access to order processing information through mobile devices.

Stage 4 – Full digitization

- Automated real-time transmission of order into order processing system;
- Automated real-time procurement of missing data;
- Automated linkage of order and existing customer information;
- Recourse to business partner information when analyzing order status (e.g. real-time order status of carrier, delivery capability of suppliers and of factories from production networks, material flow tracking);
- Automated real-time verification for orderable configuration and calculation of accurate price;
- Automated real-time check of customer's credit;
- (Automated real-time configuration of product to the customer's need or request based on standard available parts or other offered options);
- Automated real-time transmission of order confirmation;
- Automated real-time transmission of order modifications;
- Automated verification of modifications (e.g. feasibility analysis, availability check of material, capacity check);
- Automated revision of the cost situation and calculation of price adjustments;
- Automated message to inform the customer and responsible parties about decision on approval or rejection; and

- Business partner access to all the order data and real-time traceability (e.g. order status, location, delivery date, free possibilities for change, change of the delivery date, progress monitoring) via database of IoT operating system.

Stage 5 – Optimized full digitization

- Automated real-time verification of modifications based on 3D-simulation (e.g. feasibility analysis, availability check of material, capacity check);
- Automated real-time revision of cost situation and calculation of price adjustments;
- Automated analysis of new order status (e.g. postponement of the delivery date);
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of data transmission, verification of orderable configuration, cost calculation or verification of order modifications in case of failure; and
- Self-learning abilities from solved cases of failure.

Reserve inventory and determine delivery date (sD1.3/sD2.3)

"Inventory (both on hand and scheduled) is identified and reserved for specific orders and a delivery date is committed and scheduled." (SCOR, 2017, p. 2.5.8 and p. 2.5.28)

Stage 1 – Basic digitization

- Manual identification and reservation of inventory (on hand or scheduled) in company's order processing system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. availability of capacities and resources, production capacity);
- Manual scheduling of delivery date;
- Confirmation of delivery date to customer and carrier via phone, fax or e-mail; and
- Manual rescheduling of delivery date and confirmation in case of rejection by customer.

Stage 2 – Cross-department digitization

- Electronically supported identification and reservation of inventory (on hand or scheduled) in company's system;
- Electronic assembly of relevant information in a one-page format;
- Electronically supported scheduling of delivery date;
- Electronic confirmation of delivery date to customer and carrier via standardized interface; and
- Electronically supported rescheduling of delivery date and confirmation in case of rejection by customer.

Stage 3 – Horizontal and vertical digitization

- Automated identification and reservation of inventory (on hand or scheduled) in cloud-based IoT operating system;
- Automated scheduling of delivery date;

- Recourse to company-specific parameters (e.g. availability of resources, production capacity, average delivery time, electronically stored flow charts, country-specific requirements);
- Automated transmission of delivery date to customer and carrier via standardized interface;
- Automated rescheduling of delivery date and confirmation in case of rejection by customer; and
- Access to information for reservation of inventory and determination of delivery date through mobile devices.

Stage 4 – Full digitization

- Automated real-time identification and reservation of inventory (on hand or scheduled) in cloud-based IoT operating system;
- Automated real-time scheduling of delivery date;
- Recourse to carrier experience for scheduling (e.g. average transportation time, carrier availability and free capacity);
- Recourse to customer-specific data or requests (e.g. opening hours of receiving department, country-specific holidays, preferred delivery date, precautions for delivery)
- Automated real-time transmission of delivery date to customer and carrier via standardized interface;
- Automated real-time rescheduling of delivery date and confirmation in case of rejection by customer;
- Within Frozen Zone: no consideration of further customer requests due to status of shipment; and
- Postponement of delivery date by customer via access to cloud-based IoT operating system.

Stage 5 – Optimized full digitization

- Automated real-time rescheduling of delivery date in case of short-term changes (e.g. delays of sourcing, production, carrier);
- Automated real-time confirmation to customer and notification of responsible parties;

- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of inventory reservation, scheduling of delivery date or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Consolidate orders (sD1.4/sD2.4)

"The process of analyzing orders to determine the groupings that result in least cost/best service fulfillment and transportation." (SCOR, 2017, p. 2.5.9 and p. 2.5.29)

Stage 1 – Basic digitization

- Manual analysis of orders (same customer) in company's order processing system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. transportation criteria, product size and volume, delivery date, priority of distribution, special requirements [e.g. hazmat, cross-border transportation]);
- Manual comparison of data and decision making for an ideal order bundling; and
- Response to customer about most favorable variant via phone, fax or e-mail.

Stage 2 – Cross-department digitization

- Electronically supported analysis of orders (same customer) in company's system.
- Electronic assembly of relevant information in a one-page format.
- Electronically supported comparison of data and decision making for an ideal order bundling.
- Electronic response to customer about most favorable variant via standardized interface.

Stage 3 – Horizontal and vertical digitization

- Automated analysis of orders (same customer) in cloud-based IoT operating system;

- Recourse to order-specific data and parameters (e.g. transportation criteria, product size and volume, delivery date, priority of distribution, special requirements [e.g. hazmat, cross-border transportation]);
- Automated comparison of data, forecasting and decision making for an ideal order bundling;
- Automated response to customer about most favorable variant via standardized interface; and
- Access to information for order bundling through mobile devices.

Stage 4 – Full digitization

- Automated real-time analysis of orders (same customer) in cloud-based IoT operating system;
- Recourse to carrier information (e.g. real-time carrier availability and free capacity, dimensions of transport space);
- Recourse to customer requests (e.g. preferred bundles and delivery date) via access to cloud-based IoT operating system;
- Within Frozen Zone: no consideration of further customer requests due to status of shipment; and
- Automated real-time response to customer about most favorable variant.

Stage 5 – Optimized full digitization

- Automated real-time adaptation of bundles in case of short-term changes (e.g. postponement of delivery date, changes of transportation criteria);
- Automated real-time response to customer and notification of responsible parties;
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of bundles based on different criteria (e.g. cost savings, service fulfillment, customer satisfaction, recourse to parameters, carrier information, customer requests);

- Automated analysis of bundles or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Build loads (sD1.5/sD2.5)

"Transportation modes are selected and efficient loads are built." (SCOR, 2017, p. 2.5.10 and p. 2.5.30)

Stage 1 – Basic digitization

- Manual selection of transportation modes (types: overland transport (e.g. road, rail, pipeline), maritime transportation (e.g. inland waterways, ocean), air transportation, combined or intermodal transportation) in company's shipping process system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. transportation criteria, product destination, product size and volume, delivery date, priority of distribution, costs of transportation mode, efficiency, special requirements [e.g. hazmat, cross-border transportation]);
- Manual comparison of data and decision-making concerning transportation modes;
- Manual analysis of orders or order bundles (various customers) in company's shipping process system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. transportation criteria, product destination, product size and volume, delivery date, priority of distribution, special requirements (e.g. hazmat, cross-border transportation, transport volume));
- Manual comparison of data and decision making for an ideal order bundling; and
- Response to customer about most favorable variant (transportation mode, efficient load) via phone, fax or e-mail.

Stage 2 – Cross-department digitization

- Electronically supported selection of transportation modes in company's system;
- Electronic assembly of relevant information in a one-page format;

- Electronically supported comparison of data and decision making concerning transportation modes;
- Electronically supported analysis of orders or order bundles (various customers) in company's system;
- Electronic assembly of relevant information in a one-page format;
- Electronically supported comparison of data and decision making for an ideal order bundling; and
- Electronic response to customer about most favorable variant (transportation mode, efficient load) via standardized interface.

Stage 3 – Horizontal and vertical digitization

- Automated selection of transportation modes in cloud-based IoT operating system;
- Recourse to order-specific data and parameters (e.g. transportation criteria, product destination, product size and volume, delivery date, priority of distribution, costs of transportation mode, efficiency, special requirements [e.g. hazmat, cross-border transportation, status of shipment, reliability of transportation modes]);
- Automated comparison of data and decision making concerning transportation modes;
- Automated analysis of orders or order bundles (various customers) in cloud-based IoT operating system;
- Recourse to order-specific data and parameters (e.g. transportation criteria, product destination, product size and volume, delivery date, priority of distribution, special requirements [e.g. hazmat, cross-border transportation]);
- Automated comparison of data, forecasting as well as decision-making for an ideal order bundling;
- Automated response to customer about most favorable variant (transportation mode, efficient load) via standardized interface; and
- Access to information of transportation mode and efficient load through mobile devices.

Stage 4 – Full digitization

- Automated real-time selection of transportation modes in cloud-based IoT operating system;
- Recourse to carrier information (e.g. real-time carrier availability and free capacity);
- Recourse to customer requests (e.g. preferred transportation modes) via access to cloud-based IoT operating system;
- Within Frozen Zone: no consideration of further customer requests due to status of shipment;
- Automated real-time analysis of orders or order bundles (various customers) in cloud-based IoT operating system;
- Recourse to carrier information (e.g. real-time carrier free capacity, dimensions of transport space);
- Recourse to customer requests (e.g. preferred delivery date) via access to cloud-based IoT operating system; and
- Automated real-time response to customer about most favorable variant (transportation mode, efficient load).

Stage 5 – Optimized full digitization

- Automated real-time adaptation of bundles or transportation mode in case of short-term changes (e.g. postponement of delivery date, changes of transportation criteria);
- Automated real-time response to customer and notification of responsible parties;
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of bundles as well as transportation mode based on different criteria (e.g. cost savings, service fulfillment, customer satisfaction, recourse to parameters, carrier information, customer requests);
- Automated analysis of bundles, transportation mode or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Route shipments (sD1.6/sD2.6)

"Loads are consolidated and routed by mode, lane and location." (SCOR, 2017, p. 2.5.11 and p. 2.5.31)

Stage 1 – Basic digitization

- Manual route planning in company's shipping process system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. grouping of orders, transportation mode and criteria, product destination, delivery date, costs, special requirements [e.g. hazmat, cross-border transportation]);
- Manual comparison of data and decision making concerning route planning; and
- Response to customer about most favorable route via phone, fax or e-mail.

Stage 2 – Cross-department digitization

- Electronically supported route planning in company's system;
- Electronic assembly of relevant information in a one-page format;
- Electronically supported comparison of data and decision making concerning route planning; and
- Electronic response to customer about most favorable route via standardized interface.

Stage 3 – Horizontal and vertical digitization

- Automated route planning in cloud-based IoT operating system;
- Recourse to order-specific data and parameters (e.g. grouping of orders, transportation mode and criteria, product destination, delivery date, costs, special requirements [e.g. hazmat, cross-border transportation, route safety]);
- Automated comparison of data and decision-making concerning route planning;

- Automated response to customer about most favorable route via standardized interface; and
- Access to information for route planning through mobile devices.

Stage 4 – Full digitization

- Automated real-time route planning in cloud-based IoT operating system;
- Recourse to carrier information (e.g. real-time carrier availability);
- Recourse to customer requests (e.g. preferred routes) via access to cloud-based IoT operating system;
- Within Frozen Zone: no consideration of further customer requests due to status of shipment; and
- Automated real-time response to customer about most favorable route via standardized interface.

Stage 5 – Optimized full digitization

- Automated real-time rescheduling of routes in case of short-term changes (e.g. postponement of delivery date, changes of transportation criteria, delay of carrier);
- Automated real-time response to customer and notification of responsible parties;
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of planned routes based on different criteria (e.g. service fulfillment, customer satisfaction, recourse to parameters, carrier information and customer requests);
- Automated analysis of planned routes or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Select carriers and rate shipments (sD1.7/sD2.7)

"Specific carriers are selected by lowest cost per route and shipments are rated and tendered." (SCOR, 2017, p. 2.5.12 and p. 2.5.32)

Stage 1 – Basic digitization

- Manual carrier selection in company's shipping process system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. grouping of orders, transportation modes, route planning, transport criteria, mode of shipment, product destination, price, priority of distribution);
- Manual comparison of data and decision-making concerning carrier selection;
- Manual commissioning of carrier (informing about decision on approval or rejection) via phone, fax or e-mail; and
- Manual transmission of necessary product data, documents and company-specific transport specifications to the carrier via phone, fax or e-mail.

Stage 2 – Cross-department digitization

- Electronically supported carrier selection in company's system;
- Electronic assembly of relevant information in a one-page format;
- Electronically supported comparison of data and decision making concerning carrier selection;
- Electronically supported commissioning of carrier (informing about decision on approval or rejection) via standardized interface; and
- Electronic transmission of necessary product data, documents and company-specific transport specifications to the carrier via standardized interface.

Stage 3 – Horizontal and vertical digitization

- Automated carrier selection in cloud-based IoT operating system;
- Recourse to different parameters (e.g. groupings of orders, priority of distribution, transport criteria, mode of shipment, product destination, price, technical facilities for product monitoring, route practicability (shortest, fastest, resource-saving route), availability of integrated status measurement devices (e.g. monitoring of the mechanical load, moisture, GPS tracking, carrier reliability, product-specific transportation criteria, routing, means of transport and implementation of company-specific guidelines);
- Automated comparison of data and decision making concerning carrier selection;
- Automated commissioning of carrier (informing about decision on approval or rejection) via standardized interface;
- Automated transmission of necessary product data, documents and company-specific transport specifications to the carrier via standardized interface; and
- Access to information for carrier selection through mobile devices.

Stage 4 – Full digitization

- Automated real-time carrier selection in cloud-based IoT operating system;
- Recourse to carrier information (e.g. real-time carrier availability and free capacity, company-specific Incoterms);
- Recourse to customer requests (e.g. mode of shipment) via access to cloud-based IoT operating system;
- Within Frozen Zone: no consideration of further customer requests due to status of shipment;
- Automated real-time commissioning of carrier (informing about decision on approval or rejection) via standardized interface; and

- Automated real-time transmission of necessary product data, documents and company-specific transport specifications to the carrier via standardized interface.

Stage 5 – Optimized full digitization

- Automated real-time selection of carrier in case of short-term changes (e.g. postponement of delivery date, delay of carrier);
- Automated real-time response to customer and notification of responsible parties;
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of carrier selection based on different criteria (e.g. service fulfillment);
- Automated analysis of carrier selection or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Receive product from source or make (sD1.8/sD2.8)

"The activities such as receiving product, verifying, recording product receipt, determining put-away location, putting away and recording location that a company performs at its own warehouses. May include quality inspection." (SCOR, 2017, p. 2.5.13 and p. 2.5.33)

Stage 1 – Basic digitization

- Manual planning of picking waves in company's warehousing system;
- Manual rescheduling of picking waves in case of delay (e.g. sourcing or production delays);
- Product reception by storekeeper;
- Transmission of product information through manual scanning procedures (direct, visual contact);
- Manual product verification by storekeeper;
- Manual product arrangement in the warehouse based on, e.g. turnover rate, size of product;
- Manual sorting and shelving of received products;
- No product surveillance in the warehouse; and
- Manual recording of product location in the warehouse.

Stage 2 – Cross-department digitization

- Electronically supported planning of picking waves in company's system;
- Electronically supported rescheduling of picking waves in case of delay (e.g. sourcing or production delays);
- Transmission of stored product information via passive RFID transponder;
- Product verification by storekeeper supported through wearables (especially glasses);
- Relevant information situated in the field of view;
- Product arrangement by storekeeper supported through wearables (especially glasses);

- Display of storage location in warehouse and fastest route;
- Manual sorting and shelving of received products;
- Surveillance of product in the warehouse through 360° camera; and
- Electronically supported recording of product location in the warehouse.

Stage 3 – Horizontal and vertical digitization

- Automated planning of picking waves in cloud-based IoT operating system;
- Automated product reception by autonomously acting transportation system;
- Use of specific routes to navigate the transportation system;
- Interaction between vehicles for picking waves and coordination of single routes (e.g. decelerating or avoiding single vehicles;
- Automated transmission of relevant product information and documents via active RFID;
- Automated product verification via sensors;
- Automated intelligent product arrangement in warehouse based on turnover rate, size of product;
- Automated sorting and shelving of received products in RFID container;
- Product surveillance in the warehouse through sensors;
- Automated notification of responsible parties when reaching critical levels (e.g. humidity, temperature);
- Automated recording of product location in warehouse system; and
- Access to information for picking waves and storage of products through mobile device.

Stage 4 – Full digitization

- Automated real-time planning of picking waves in cloud-based IoT operating system;

- Automated real-time rescheduling of picking waves in case of delay (e.g. sourcing or production delays);
- Automated real-time transmission of relevant product information and documents via active RFID;
- Real-time product surveillance in the warehouse through sensors; and
- Automated real-time notification of responsible parties when reaching critical levels (e.g. humidity, temperature).

Stage 5 – Optimized full digitization

- Automated real-time rescheduling of picking waves in case of delay (e.g. sourcing or production delays, carrier delays);
- Automated route analysis of autonomously acting transportation system;
- Automated real-time optimization of transportation system routes and of warehouse space for optimized utilization;
- Automated rearrangement of products for an ideal autonomously acting transportation system with an optimized material flow;
- Automated real-time notification and initiation of countermeasures when product reaches critical levels (e.g. humidity, temperature);
- Automated analysis of surveillance data or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Pick product (sD1.9/sD2.9)

"The series of activities including retrieving orders to pick, determining inventory availability, building the pick wave, picking the product, recording the pick and delivering product to shipping in response to an order." (SCOR, 2017, p. 2.5.14 and p. 2.5.34)

Stage 1 – Basic digitization

- Manual retrieval of the required order;
- Manual determination of inventory availability;
- Manual planning of picking waves in the company's shipping system;
- Manual rescheduling of picking waves in case of delay;
- Product collection by picker from storage location and delivery to shipping;
- Product verification by picker;
- Manual acquisition of picking the order from warehouse; and
- Manual product delivery to the previously defined loading point.

Stage 2 – Cross-department digitization

- Electronically supported retrieval of the required order;
- Electronically supported determination of inventory availability;
- Electronically supported planning of picking waves in the company's system;
- Electronically supported rescheduling of picking waves in case of delay;
- Product collection by picker supported through wearables (especially glasses);
- Relevant information situated in the field of view;
- Display of production location in warehouse and fastest route or picking waves;
- Product verification through connection of glasses with passive RFID transponder;

- Electronically supported acquisition of picking the order from warehouse; and
- Electronically supported product delivery to the previously defined loading point.

Stage 3 – Horizontal and vertical digitization

- Automated retrieval of the required order;
- Automated determination of inventory availability;
- Automated planning of picking waves in cloud-based IoT operating system;
- Automated rescheduling of picking waves in case of delay (e.g. sourcing or production delay);
- Product collection from RFID container by autonomously acting transportation system;
- Use of specific routes to navigate the transportation system through warehouse;
- Interaction between vehicles for picking waves and coordination of single routes (e.g. decelerating or avoiding single vehicles);
- Automated product verification through sensors;
- Automated acquisition of picking the order from warehouse;
- Automated product delivery to previously defined loading point; and
- Access to information for product picking through mobile devices.

Stage 4 – Full digitization

- Automated real-time retrieval of the required order;
- Automated real-time determination of inventory availability;
- Automated real-time planning of picking waves in cloud-based IoT operating system;
- Automated real-time rescheduling of picking waves in case of delay (e.g. delay of sourcing, production or carrier); and
- Recourse to carrier information (e.g. carrier’s expected arrival time) for automated scheduling of picking waves.

Stage 5 – Optimized full digitization

- Automated real-time rescheduling of picking waves in case of delay (e.g. carrier delays);
- Automated real-time planning of picking waves in cloud-based IoT operating system;
- Automated route analysis of autonomously acting transportation system;
- Automated real-time optimization of transportation system routes;
- Automated analysis of planned picking waves, planned routes and product delivery to loading point or data transmission;
- Automated analysis of planned picking waves, planned routes and product delivery to loading point or data transmission in case of failure; and
- Self-learning abilities from solved cases of failure.

Pack product (sD1.10/sD2.10)

"The activities such as sorting/combining the products, packing/kitting the products, paste labels, barcodes etc. and delivering the products to the shipping area for loading." (SCOR, 2017, p. 2.5.15 and p. 2.5.35)

Stage 1 – Basic digitization

- Manual sorting and combining of products to efficient bundles;
- Manual procurement and analysis of relevant information from various IT systems
- Product verification by picker;
- Manual configuration of an efficient (space saving) and resource-conserving packaging/ packaging units with regard to product and logistic requirements, profitability and sustainability;
- Clear product identification via optical procedure (e.g. barcode, QR code);
- Electronic creation of product label;
- Transmission of product information through manual scanning procedures (direct, visual contact);
- Manual verification whether label information's correspond to content of supporting documents;
- Product surveillance during shipping not possible;
- Manual planning of picking waves in company's warehousing system; and
- Product collection by picker from packaging location and delivery to clearly marked loading area.

Stage 2 – Cross-department digitization

- Electronically supported sorting and combining of products to efficient bundles;
- Picker supported through wearables (especially glasses);
- Relevant information situated in the field of view;
- Display of necessary information for sorting and combining the right products;

- Product verification through connection of glasses with passive RFID transponder of product;
- Electronically supported configuration of an efficient (space saving) and resource-conserving packaging/packaging units with regard to product and logistic requirements, profitability and sustainability;
- Integration of passive RFID transponder into packaging;
- Clear product identification via radio-based procedure (e.g. passive RFID);
- Transmission of stored information (e.g. delivery note) via passive RFID transponder;
- Electronically supported verification whether label information's correspond to content of supporting documents;
- Product surveillance during shipping with 360° camera;
- Electronically supported planning of picking waves in company's system;
- Product collection by picker supported through wearables (especially glasses) and delivery to clearly marked loading area;
- Relevant information situated in the field of view; and
- Display of warehouse location of the product and fastest way to the loading area.

Stage 3 – Horizontal and vertical digitization

- Automated sorting and combining of products to efficient bundles by autonomously acting robot order-picking system;
- Product verification through active RFID transponder;
- Automated configuration of an efficient (space saving) and resource-conserving packaging/packaging units;
- Recourse to the packaging-specific parameters (e.g. profitability, sustainability, country-specific regulations, transport mode, price);
- Automated integration of sensors into packaging for monitoring changing circumstances;

- Sensor-reading of changing circumstances or environmental stimuli (e.g. humidity, temperature, mechanical load, shocks, tilts);
- Automated identification via sensors if packaging can be reused or recycled;
- Clear product identification via radio-based procedure (e.g. active RFID);
- Automated transmission of stored information (e.g. production and delivery information, order information) and documents (e.g. shipping documents) to RFID reader;
- Automated product surveillance during shipping via integrated sensors;
- Automated planning of picking waves in cloud-based IoT operating system;
- Product collection from RFID container by autonomously acting transportation system and delivery to clearly marked loading area;
- Use of specific routes to navigate the transportation system to loading area;
- Interaction between vehicles for picking waves and coordination of single routes (e.g. decelerating or avoiding single vehicles); and
- Access to information of product packaging through mobile devices.

Stage 4 – Full digitization

- Automated real-time sorting and combining of products to efficient bundles by autonomously acting robot order-picking system;
- Recourse to carrier information (e.g. delay, current utilization) for automated resorting and recombining of products to efficient bundles by robot order-picking system;
- Automated real-time configuration of an efficient (space saving) and resource-conserving packaging/packaging units;
- Recourse to customer requests or requirements (e.g. customized packaging design, receiving department's measurement,

customer's storage, customer-specific texts) for product packaging via access to cloud-based IoT operating system;
- Recourse to carrier experience (e.g. manageability of product packaging) for product packaging; and
- Recourse to carrier information (e.g. delay) for rescheduling the product collection and delivery to clearly marked loading area or temporary storage.

Stage 5 – Optimized full digitization

- Automated real-time selection of the most suitable and cost-effective packaging/ packaging units obtained by use of 3D-simulation;
- Automated real-time influence of carrier experience (e.g. manageability of product packaging) on packaging decisions;
- Automated interchange of the integrated IT system with IT systems of other factories for identification of practicable best practices and deduction of necessary measures;
- Automated search for new potentials and trends with regards to packaging solutions/ improvements;
- Automated evaluation and implementation on the basis of sustainability and profitability;
- Automated analysis of data transmission, combination of products, configuration of packaging or integration of sensors in case of failure;
- Self-learning abilities from solved cases of failure;
- Automated route analysis of the autonomously acting transportation system;
- Automated real-time optimization of transportation system routes; and
- Automated real-time rescheduling of picking waves in case of short-term changes.

Load vehicle/product and generate shipping docs (sD1.11/sD2.11)

"The series of tasks including placing/loading product onto modes of transportation, and generating the documentation necessary to meet internal, customer, carrier and government needs. Shipping documentation includes the invoice. Optionally verify customer credit." (SCOR, 2017, p. 2.5.16-17 and p. 2.5.36)

Stage 1 – Basic digitization

- Message to carrier including loading area's location data and relevant information via phone, fax or e-mail;
- Manual planning of outbound logistics in company's shipping system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. number of orders, transportation mode, carrier's arrival time);
- Manual rescheduling of outbound logistics in case of internal delays;
- Manual notification about rescheduling to responsible parties;
- Transmission of production data and accompanying documents through manual scanning procedures;
- Loading of product onto transportation mode by picker;
- Manual documentation of the loading process;
- Manual inspection of the "legal safety standards" checklist (e.g. load security, transportation quality) for supply chain security; and
- Manual documentation of the execution and defects as well as development of measures in case of gaps.

Stage 2 – Cross-department digitization

- Message to carrier including loading area's location data and relevant information via standardized interface;
- Electronically supported planning of outbound logistics in company's system;

- Electronic assembly of relevant data in a one-page format;
- Electronically supported rescheduling of outbound logistics in case of internal delays;
- Electronically supported notification about rescheduling to responsible parties;
- Transmission of product data and accompanying documents via passive RFID transponder;
- Loading of product onto transportation modes by picker (supported through wearables – especially glasses);
- Relevant information situated in the field of view;
- Display of required loading equipment (e.g. lifting tool) and accurate lifting and carrying of (heavy) loads;
- Electronically supported documentation of the loading process; and
- Electronically supported documentation of the execution and defects as well as development of measures in case of gaps.

Stage 3 – Horizontal and vertical digitization

- Automated message to carrier including loading area's location data and relevant information via standardized interface;
- Automated planning of outbound logistics in cloud-based IoT operating system;
- Automated rescheduling of outbound logistics in case of internal delays;
- Automated notification about rescheduling to responsible parties;
- Automated transmission of product data and accompanying documents via active RFID;
- Automated planning of product loading onto transportation mode and of necessary loading equipment (e.g. lifting tool);
- Loading of product onto transportation mode by picker supported through intelligent containers with self-unloading function;
- Automated documentation of the loading process;

- Automated inspection of the ‘legal safety standards’ checklist for supply chain security;
- Automated documentation of the execution and defects as well as development of measures in case of gaps; and
- Access to information for product loading via mobile devices.

Stage 4 – Full digitization

- Automated real-time connection of carrier’s vehicle information with product’s location data and provision of map information about loading area to driver’s mobile device;
- Automated execution of safety checks (e.g. identity control through face recognition) via the driver’s mobile device;
- Display of final unloading station including opening hours of receiving department, calculated route and customer-specific requirements;
- Automated real-time planning of outbound logistics in cloud-based IoT operating system;
- Automated real-time notification about rescheduling to responsible parties;
- Integration of carrier into the safety concept: driver’s confirmation about safety concept via mobile device;
- Possibility for carrier to inform himself about the current safety concept and to transfer relevant safety checks via access to the cloud-based IoT operating system; and
- Automated notifications about changes in current safety concept.

Stage 5 – Optimized full digitization

- Automated loading of product into transportation mode by intelligent containers with self-unloading function;
- Automated analysis of data transmission, planning of outbound logistics as well as of product loading or documentation process in case of failure;
- Self-learning abilities from solved cases of failure; and

- Automated real-time rescheduling of outbound logistics in case of deviations (e.g. delay of carrier).

Ship product (sD1.12/sD2.12)

"The process of shipping the product to the customer site." (SCOR, 2017, p. 2.5.18 and p. 2.5.37)

Stage 1 – Basic digitization

- Tracking of product and product-specific transportation criteria (e.g. temperature, tilt, moisture) during shipping not possible;
- Manual procurement of data; and
- Manual evaluation of logistic indicators (e.g. transport duration, transport quality).

Stage 2 – Cross-department digitization

- Tracking of product via 360° camera during shipping;
- Tracking of product-specific transportation criteria not possible;
- Electronic assembly of logistic indicators in a one-page format;
- Manual identification of deviations of logistic indicators; and
- Manual derivation and implementation of corrective measures.

Stage 3 – Horizontal and vertical digitization

- Automated tracking of product and product-specific transportation criteria during shipping via sensors;
- Continuously transmission of information on product state to responsible parties;
- Automated identification of deviations of logistics indicators;
- Automated derivation of corrective measures;
- Manual implementation of corrective measures;
- Automated adaptation of the route to unforeseeable changes/external factors of conditions (e.g. political commotion, natural disasters);
- Automated rerouting if rapid changes of conditions require such measures without an increase of shipping costs; and
- Access to tracking information via mobile devices.

Stage 4 – Full digitization

- Automated real-time tracking of product and product-specific transportation criteria during shipping via sensors;
- Automated identification of deviations of logistics indicators;
- Warning messages to drivers' mobile device if product conditions turn critical;
- Automated derivation of corrective measures;
- Automated transmission of notifications to responsible parties;
- Automated decision about replacement for initial product, provision of spare parts or whether a service technician can solve the problem on the ground;
- Automated initiation of necessary measures based on the preceding decision;
- Automated real-time rerouting if rapid changes of conditions require such measures without an increase of shipping costs;
- Automated message to contracting company with alternative options choosing the preferred one if shipping costs change;
- Real-time tracking of product status by customer, carrier and contracting company via cloud-based IoT operating system; and
- Real-time evaluation of carrier's performance and transportation structure data.

Stage 5 – Optimized full digitization

- Self-learning abilities based on real-time evaluation of logistic indicators;
- Automated real-time influence on carrier information and parameters (e.g. carrier loyalty) which are used for decision making (e.g. carrier selection);
- Automated real-time rescheduling of picking waves in case of short-term changes (e.g. delay);
- Automated real-time route analysis of shipping;
- Automated real-time optimization of these shipping routes;
- Automated analysis of tracking information, data transmission or automated decisions in case of failure; and

- Self-learning abilities from solved cases of failure.

Receive and verify product by customer (sD1.13/sD2.13)

"The process of receiving the shipment by the customer (either at customer site or at shipping area in case of self-collection) and verifying that the order was shipped complete and that the product meets delivery terms." (SCOR, 2017, p. 2.5.19 and p. 2.5.38)

Stage 1 – Basic digitization

- Message to customer about delivery time and destination (either at customer site or at shipping area in case of self-collection) as well as actual product data via phone, fax or e-mail;
- Verification regarding complete delivery (e.g. right product, right quantity, right quality) and fulfillment of delivery terms by employee of receiving department;
- Documentation of product handover by employee of receiving department;
- Manual documentation of damages in case of loss;
- Manual decision about further procedure regarding the product; and
- Manual cause analysis and deduction of improvement potential.

Stage 2 – Cross-department digitization

- Message to customer about delivery time and destination as well as actual product data via standardized interface;
- Electronically supported documentation of product handover;
- Electronically supported documentation of damages in case of loss;
- Electronically supported decision about further procedure regarding the product; and
- Electronically supported cause analysis and deduction of improvement potential.

Stage 3 – Horizontal and vertical digitization

- Automated message to customer about of delivery time (including delays) and destination;
- Automated transmission of actual product data (e.g. dimensions and weight of product) and accompanying documents as well as hints for unloading (e.g. required unloading equipment);
- Automated notification for employee of receiving department upon arrival (e.g. product status, complete delivery, information about existing damages, delivery of spare parts, arrival of service technician);
- Automated verification regarding complete delivery and fulfillment of delivery terms through active RFID;
- Automated documentation of product handover in cloud-based IoT operating system;
- Automated preparation of product return in case of damages and transmission of required documents to customer;
- Automated documentation and transmission of logistic complaints; and
- Automated cause analysis of complaint including evaluation of RFID chip data (e.g. time and location of production, time and location of product packaging) and sensor data
- Access to information of product receive through mobile devices.

Stage 4 – Full digitization

- Automated real-time message to customer about of delivery time (including delays) and destination;
- Automated real-time transmission of actual product data (e.g. dimensions and weight of product) and accompanying documents as well as hints for unloading (e.g. required unloading equipment);
- Automated real-time notification for employee of receiving department upon arrival (e.g. product status, complete delivery, information about existing damages, delivery of spare parts, arrival of service technician); and

- Automated message to carrier about future improvement suggestions based on cause analysis.

Stage 5 – Optimized full digitization

- Self-learning abilities based on real-time evaluation of logistic indicators;
- Automated deduction of improvement potential based on analyzed data;
- Automated deduction of necessary measures to lower damages in transit and optimize packaging;
- Automated real-time implementation of corrective measures;
- Automated interchange of the integrated IT system with IT systems of other factories for an identification of practicable best practices;
- Automated search for new potentials and trends with regards to packaging solutions/improvements; synchronization via the cyber-physical-systems of the factory;
- Automated review of the degree of the improvement and measure implementation (target-actual comparison) by integrated IT system;
- Automated analysis of data transmission or automated decisions in case of failure; and
- Self-learning abilities from solved cases of failure.

Install product (sD1.14/sD2.14)

"When necessary, the process of preparing, testing and installing the product at the customer site. The product is fully functional upon completion." (SCOR, 2017, p. 2.5.20 and p. 2.5.39)

Stage 1 – Basic digitization

- Manual scheduling of product installation date in company's shipping system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. availability of service technician);
- Confirmation of product installation date to customer via phone, fax or e-mail;
- Manual rescheduling of product installation date and confirmation in case of rejection by customer;
- Manual compilation of required documents, equipment for service technician as well as spare parts (if necessary);
- Manual product installation, replacement of spare parts (if necessary) and testing by service technician;
- Documentation of product installation by service technician;
- Preparation of action plan by service technician in case of not fully functional product; and
- Order of necessary spare parts and manual rescheduling of product installation date.

Stage 2 – Cross-department digitization

- Electronically supported scheduling of product installation date in company's system;
- Electronic assembly of necessary information in a one-page format;
- Electronic confirmation of product installation date to customer via standardized interface;
- Electronically supported rescheduling of product installation date and confirmation in case of rejection by customer;

- Electronically supported compilation of required documents, equipment for service technician as well as spare parts (if necessary);
- Product installation by service technician supported through wearables (especially glasses);
- Relevant installation information situated in the field of view;
- Electronically supported documentation of product installation by service technician;
- Electronically supported preparation of action plan in case of not fully functional product; and
- Electronically supported order of necessary spare parts and electronically supported rescheduling of product installation date.

Stage 3 – Horizontal and vertical digitization

- Automated scheduling of product installation date in cloud-based IoT operating system;
- Recourse to company-specific parameters (e.g. availability of service technician, delivery time of spare parts);
- Automated transmission of product installation date to customer via standardized interface;
- Automated rescheduling of product installation date and confirmation in case of rejection by customer;
- Automated compilation of required documents, equipment for service technician as well as spare parts (if necessary);
- Automated transmission of relevant product data and hints for installing the product to service technician;
- Automated documentation of product installation in cloud-based IoT operating system;
- Automated preparation of action plan in case of not fully functional product;
- Automated order of necessary spare parts and automated rescheduling of product installation date; and
- Access to information for product installation through mobile devices.

Stage 4 – Full digitization

- Automated real-time scheduling of product installation date in cloud-based IoT operating system;
- Recourse to service technician data and experience (e.g. average product installation time);
- Recourse to customer-specific data or requests (e.g. opening hours of the receiving department, country-specific holidays, preferred product installation date);
- Within Frozen Zone: no consideration of further customer requests due to status of shipment;
- Postponement of product installation date by customer via access to cloud-based IoT operating system; and
- Automated real-time transmission of relevant product data and hints for installing the product to service technician.

Stage 5 – Optimized full digitization

- Automated real-time rescheduling of product installation date in case of short-term changes;
- Automated real-time notification of responsible parties;
- Autonomous introduction of the respective rescheduling by the cognitive IT system and synchronization with other CPS;
- Automated analysis of scheduling of product installation date, data transmission or documentation of product installation in case of failure; and
- Self-learning abilities from solved cases of failure.

Invoice (sD1.15/sD2.15)

"A signal is sent to the financial organization that the order has been shipped and that the billing process should begin and payment be received or be closed out if payment has already been received. Payment is received from the customer within the payment terms of the invoice." (SCOR, 2017, p. 2.5.21 and p. 2.5.40)

Stage 1 – Basic digitization

- Manual creation of invoice in company's warehousing system;
- Manual procurement and analysis of relevant information from various IT systems (e.g. actual costs) and consideration of country-specific regulations;
- Transmission of invoice to customer via phone, fax or e-mail;
- Manual verification of money receipt within the payment terms;
- Manual creation of payment reminder if payment terms are overdue; and
- Transmission of payment reminder to customer via phone, fax or e-mail.

Stage 2 – Cross-department digitization

- Electronically supported creation of invoice in company's system;
- Electronic assembly of relevant information in a one-page format and consideration of country-specific regulations;
- Electronic transmission of invoice to customer via standardized interface;
- Electronically supported verification of money receipt within the payment terms;
- Electronically supported creation of payment reminder if payment terms are overdue; and
- Electronic transmission of payment reminder to customer via standardized interface.

Stage 3 – Horizontal and vertical digitization

- Automated creation of invoice in cloud-based IoT operating system;
- Recourse to actual data (e.g. weight, size, shipping route, actual costs) as well as consideration of country-specific regulations;
- Automated transmission of invoice to customer via standardized interface;
- Automated verification of money receipt within the payment terms;
- Automated creation of payment reminder if payment terms are overdue; and
- Automated transmission of payment reminder to customer via standardized interface
- Access to invoice information through mobile devices.

Stage 4 – Full digitization

- Automated real-time creation of invoice in cloud-based IoT operating system;
- Choice of a predetermined invoice model by customer via cloud-based IoT operating system;
- Automated real-time transmission of invoice to customer;
- Automated real-time verification of money receipt within the payment terms;
- Automated real-time creation of payment reminder if payment terms are overdue;
- Automated real-time transmission of payment reminder to customer via standardized interface; and
- Access to invoice information for customer via cloud-based IoT operating system.

Stage 5 – Optimized full digitization

- Automated analysis of data transmission, creation of payment or payment reminder in case of failure; and

- Self-learning abilities from solved cases of failure.

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Article II. Digitization in Outbound Logistics – Application of an Industry 4.0 Maturity Model for the Delivery Process

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Abstract.

Purpose. Available maturity models in the context of Industry 4.0 primarily focus on manufacturing processes. A research gap exists with regard to outbound logistics. This paper applies a maturity model that has been designed to support the digitization of the outbound logistics processes. The validation of the model in business practice completes the model's development.

Design/methodology/approach. This work embraces a qualitative research design approach. In this context, it conducts a single case study. The case refers to a large multinational manufacturer of industrial electric equipment, which considers itself as one the most digitized companies in the industry.

Findings. The model appears to be applicable (1) to describe the status quo of the enterprise's digitization capabilities in outbound logistics, (2) to develop a corporate vision for delivery logistics excellence, (3) to provide guidance on the development path, and (4) to compare capabilities between different company sites.

Research limitations/implications. The model has solely been applied to two sites of one company. However, it seems applicable to other organizations as well. Nonetheless, additional case studies are necessary to verify the model's generalizability.

Practical implications. The case study provides an example of how to develop a roadmap towards delivery process excellence in the digital age ahead.

Original/value. The applied maturity model complements approaches that focus on digitization of the manufacturing processes as well as logistics maturity models. The case study is of value for organizations that intend to build Industry 4.0 capabilities in outbound logistics, which has played a minor role so far.

Keywords. Industry 4.0 · Digitization · Maturity Model · Outbound Logistics · Delivery Process

II.1 Introduction

Digitization affects all parts of the business world and disruptively changes the process of value creation (Kagermann et al., 2013). At the heart of this development is the interconnection of the real and the virtual world through innovations in the information and telecommunications technology. In business practice, digitization is particularly advanced in the production process. Most notably Cyber-Physical Systems (CPS) and the Internet of Things (IoT) are shaping a fourth industrial revolution to which various authors refer to as "Industry 4.0" (e.g., Almada-Lobo, 2015; Gökalp et al., 2017; Hermann et al., 2016). However, digitization is by no means limited to manufacturing but will inevitably expand to other processes. If the vision of Industry 4.0 is to be realized, the entire supply chain has to evolve towards a connected and smart ecosystem (Pan et al., 2017). Herein, the logistics processes play an integral role as connecting elements (Glistau & Coello Machado, 2018; Nicoletti, 2018; Pujo & Ounnar, 2018; Strandhagen et al., 2017).

On their way towards supply chain ecosystems companies require tools that help identifying transformation gaps. Herein, maturity models can be of great support. Over the past years, various CPS, IoT, and Industry 4.0 maturity models have been developed and presented in literature (e.g., Leyh et al., 2016; Katsma et al., 2011). However, there is a research gap with regards to maturity models in logistics (Gilchrist, 2016), particularly if they are to take the current digitization trends into account. This is of particular interest as McCormack et al. (2008) found that the delivery process's maturity has a higher impact on business performance than other supply chain processes. This prevalent research gap motivated the development of the Delivery Process Maturity Model (DPMM) 4.0. As an integral part of the development process, which was guided by de Bruin et al. (2005), it is necessary to validate the model in business practice. This final development step is achieved with this work. Herein, we conduct a case study, which is by far the most common method to validate maturity models and is "[...] able to deliver useful results" (Wendler, 2012, p. 1332).

This study contributes to the available literature by incorporating digitization efforts into maturity models for logistics. Besides, it complements the existing CPS, IoT, and Industry 4.0 maturity models and thus represents a further step towards a fully digitized supply chain. It also contributes to case study research in general by providing insights into the current outbound logistics digitization efforts at one of the world's leading electric equipment manufacturers.

The remainder of this paper is structured as follows: The second chapter provides the theoretical background with a focus on Industry 4.0 and logistics. The third chapter briefly introduces to the DPMM 4.0. Thereafter, the case study as the chosen method to validate the maturity model is introduced. Chapter 5 outlines the results of the DPMM 4.0 application. The paper summarizes the findings, points out theoretical and managerial implications, and proposes future research opportunities.

II.2 Theoretical Background

The Concept of Industry 4.0

The term "Industry 4.0" has been created by the German Federal Ministry of Education and Research and indicates a new era of industrialization (Oesterreich & Teuteberg, 2016). Thereby, Industry 4.0 is enabled by CPS and IoT technologies, which are integrated in industrial processes (Gökalp et al., 2017). Apart from these two, other essential Industry 4.0 technologies are cloud computing, big data, augmented reality, machine learning, cyber security, autonomous robots and simulation (Gilchrist, 2016; Gökalp et al., 2017). Through the interplay of these technologies the automation and digitization of the manufacturing processes are increased and "[...] a highly flexible production model of personalized and digital products and services, with real-time interactions between people, products and devices during the production process" (Zhou et al., 2015, p. 2147) is facilitated. Overall, Industry 4.0 depicts a new concept to reach higher information transparency and flexibility with a "[...] significant impact on supply chains, business models and processes [...]" (Gökalp et al., 2017, p. 129).

Logistics in the Context of Industry 4.0

Logistics comprises the "[...] process of strategically managing the procurement, movement and storage of materials, parts and finished inventory (and the related information flows) through the organization and its marketing channels in such a way that current and future profitability are maximized through the cost-effective fulfilment of orders." (Christopher, 2016, p. 2). Ernst and Kamrad (2000) distinguish between inbound and outbound logistics (Ernst & Kamrad, 2000). The former concentrates on the material flow that supplies the production processes, while the latter focuses on the delivery to the customer (Ernst and Kamrad, 2000). McCormack et al. (2008) emphasize that the delivery process's maturity has a higher impact on business performance than other supply chain processes.

Digitization also affects logistics (Glistau & Coello Machado, 2018; Nicoletti, 2018; Strandhagen et al., 2017). It has the potential to significantly improve efficiency when matching demand and supply through the seamless integration of several logistics actors. Some authors refer to this as cyber-physical logistic systems (e.g., Pujo & Ounnar, 2018), which pursue the goal of increasing process intelligence, connectedness and responsiveness. This pursued state of excellence requires embedded, linked, autonomously acting IT-systems to achieve end-to-end supply chain transparency and self-regulation (Göçmen & Erol, 2018; Hofmann & Rüsch, 2017; Pujo & Ounnar, 2018).

II.3 The Delivery Process Maturity Models (DPMM) 4.0

To develop into the next generation of logistics systems, decision-makers require tools that support the realignment, reconfiguration, and renewal of existing capabilities. In general, maturity models contribute to these purposes. While several available models cover digitization on the strategic level (Klötzer & Pflaum, 2017), others refer to CPS and IoT in manufacturing (e.g., Ganzarain & Errasti, 2016; de Carolis et al., 2017) and IT capabilities (e.g., Leyh et al., 2016; Weber et al., 2017). The existing logistics maturity models have not taken into account current digitization trends (e.g., van Landeghem & Persoons, 2001; Battista et al., 2012).

Motivated by this research gap the authors developed a model with a focus on outbound logistics: the Delivery Process Maturity Model (DPMM) 4.0. The development process was methodologically guided by de Bruin et al. (2005). While the first four stages (scope, design, populate, and test) are extensively documented in a separate essay (Asdecker & Felch, 2018), this paper is supposed to verify the model in business practice, which is the final development step (populate). Therefore, the model will only be briefly introduced before being applied in a case study.

The peculiarity of the DPMM 4.0 is its flexibility of the modelling architecture. Unlike other models, it can be adapted to the specific needs of a supply chain, which is derived from its reference to the Supply Chain Operations Reference (SCOR) framework (SCOR, 2017). The structure of SCOR follows a modular principle. It contains six top-level process types that can be further subdivided into more detailed process categories and process elements (SCOR, 2017). The DPMM 4.0 adopts the delivery process elements and distinguishes between three activity dimensions: order processing, warehousing, and shipping (Figure II.1).

Order Processing	Warehousing	Shipping
• Process inquiry and quote (sD1.1/sD2.1) • Receive, enter (,configure) and validate order (sD1.2/sD2.2) • Reserve inventory and determine delivery date (sD1.3/sD2.3) • Consolidate orders (sD1.4/sD2.4) • Invoice (sD1.15/sD2.15)	• Receive product from source or make (sD1.8/sD2.8) • Pick product (sD1.9/sD2.9) • Pack product (sD1.10/sD2.10)	• Build loads (sD1.5/sD2.5) • Route shipments (sD1.6/sD2.6) • Select carriers and rate shipments (sD1.7/sD2.7) • Load product/vehicle & generate shipping docs (sD1.11/sD2.11) • Ship product (sD1.12/sD2.12) • Receive and verify product by customer (sD1.13/sD2.13) • Install product (sD1.14/sD2.14)

Figure II.1. Overview of the three dimensions and their respective elements

For each of the three dimensions a vision for the highest maturity stage is derived, which is based on available literature and own empirical work. The content of the lower levels has been derived according to these three principles: the lower the maturity stage, (1) the more human interventions are necessary, (2) the lower is the inter- and intra-organizational integration, and (3) the less automatized are data and information flows. Thereafter, the populated model's comprehensibility, comprehensiveness, relevance, consistency, systematic structure, detailedness, conceptual reliability, and applicability were empirically tested with satisfactory results. Figure II.2 summarizes the final DPMM 4.0.

During a maturity assessment, participants are presented specific statements for their relevant process elements that have to be rated on a four-tiered Likert scale (0="not implemented"; 1="partly implemented"; 2="for the most part implemented"; 3="fully implemented"). To provide a deeper insight into the assessment Table II.1 provides exemplary assessment statements of one of the most fundamental activities in outbound logistics: the picking process (sD1.9/sD2.9 Pick product).

	Order processing (OP)	Warehousing (W)	Shipping (S)
Stage 1 – Basic digitization	OP is not digitized; Manual data exchange between OP and other departments; Enterprise system supports only OP (department-specific)	W is not digitized; Manual data exchange between W and other departments; Enterprise system supports only W (department-specific)	S is not digitized; Manual data exchange between S and other departments; Enterprise system supports only S process (department-specific)
Stage 2 – Cross-department digitization	OP is digitally supported; Electronic data exchange between OP and other departments; Department-wide integration of OP into enterprise systems	W is digitally supported; Electronic data exchange between W and other departments; Department-wide integration of W into enterprise systems	S is digitally supported; Electronic data exchange between S and other departments; Department-wide integration of S into enterprise systems
Stage 3 – Horizontal and vertical digitization	OP is continuously digitally supported; Automated data flow of within the company (e.g., order confirmation); Shared, integrated inter-faces (e.g., receipt of orders); Recourse to company-specific data for OP (e.g., determination of delivery date); Company-wide integration of OP into cloud-based IoT operating system; Access to OP information through mobile device	W is continuously digitally supported; Automated data flow within the company (e.g., planning picking waves); Recourse to company-specific data for W (e.g., product storage); Company-wide integration of W into cloud-based IoT operating system; Access to W information through mobile device	S is continuously digitally supported; Automated data flow within the company (e.g., planning transportation mode); Recourse to company-specific data for S process (e.g., delivery date); Automated monitoring for full traceability; Company-wide integration of S into cloud-based IoT operating system; Access to S information through mobile device
Stage 4 – Full digitization	Automated real-time OP is continuously digitally supported; Automated real-time data flow; Recourse to customer-specific data as well as business partner data for comprehensive OP (e.g., carriers' capacity); Supply chain-wide integration of OP into cloud-based IoT operating system	Automated real-time W is continuously digitally supported; Automated real-time data flow; Recourse to customer-specific data for comprehensive W (e.g., customized packaging); Supply chain-wide integration of W into cloud-based IoT operating system	Automated real-time S is continuously digitally supported; Automated real-time data flow; Recourse to customer-specific data as well as business partner data for comprehensive S (e.g., customer's preferred routes); Supply chain-wide integration of S into cloud-based IoT operating system
Stage 5 – Optimized full digitization	Automated real-time OP is continuously digitally supported within the supply chain; Real-time simulation for decision making (e.g., order confirmation); Real-time optimization (e.g., determination of delivery date); Self-learning abilities from solved cases; Supply chain-wide integration of OP into self-optimizing cloud-based IoT operating system	Automated real-time W is continuously digitally supported within the supply chain; Real-time simulation for decision making (e.g., cost-effective packaging); Real-time optimization (e.g., routes of autonomously acting transportation system); Real-time self-adjustment to changing environment; Self-learning abilities from solved cases; Supply chain-wide integration of W into self-optimizing cloud-based IoT operating system	Automated real-time S is continuously digitally supported within the supply chain; Real-time simulation for decision making (e.g., efficient grouping of orders); Real-time optimization (e.g., routes of autonomously acting transportation system); Real-time self-adjustment to changing environment; Self-learning abilities from solved cases; Supply chain-wide integration of S into self-optimizing cloud-based IoT operating system

Figure II.2. Overview of the final model

Statement ID	Statements
sD1.9/sD2.9-01	Automated real-time retrieve of the required order and determination of inventory availability
sD1.9/sD2.9-02	Automated real-time planning of picking waves in cloud-based IoT operating system
sD1.9/sD2.9-03	Use of carrier information (e.g., carrier's expected arrival time) for automated scheduling of picking waves
sD1.9/sD2.9-04	Automated real-time rescheduling of picking waves in case of delay (e.g., delay of production or carrier)

Table II.1. Exemplary assessment statements to measure the process element sD1.9/sD2.9

The assessments are transferred into maturity scores based on the following procedure. First, the relevant SCOR process elements in the dimensions $i=\{1,2,3\}$ are assigned the consecutive index $j(i)=\{1,...,J(i)\}$. Second, the provided $k(j(i))=\{1,...,K(j(i))\}$ assessment statements are evaluated on the previously mentioned four-tiered Likert scale. Third, the assessments $as_{i,j(i),k(j(i))}$ are converted into percentage scores for each model element, dimension, and the entire process. Table II.2 provides the calculation formulas.

Fourth, the scores are converted into a maturity stage. With the five stages describing a path towards excellence, the scale is evenly distributed. The first stage corresponds to a score between 0 and 20 %, the second stage to a score between 20 and 40 %, the third stage to a score between 40 and 60 %, the fourth stage to a score between 60 and 80 %, and the fifth stage to a score between 80 and 100 %. The following case study will further illustrate the model's applicability.

Potential element score $PES_{i,j(i)}$	$PES_{i,j(i)} = K\left(j(i)\right) \cdot 3$	$\forall\, i, j(i)$
Achieved element score $AES_{i,j(i)}$	$AES_{i,j(i)} = \sum_{k(j(i))=1}^{K(j(i))} as_{i,j(i),k(j(i))}$	$\forall\, i, j(i)$
Relative element score $RES_{i,j(i)}$	$RES_{i,j(i)} = \frac{AES_{i,j(i)}}{PES_{i,j(i)}} \cdot 100\,\%$	$\forall\, i, j(i)$
Relative dimension score RDS_i	$RDS_i = \frac{\sum_{j(i)=1}^{J(i)} AES_{i,j(i)}}{\sum_{j(i)=1}^{J(i)} PES_{i,j(i)}} \cdot 100\,\%$	$\forall\, i$
Total relative process score TRPS	$TRPS = \frac{\sum_{i=1}^{3} \sum_{j(i)=1}^{J(i)} AES_{i,j(i)}}{\sum_{i=1}^{3} \sum_{j(i)=1}^{J(i)} PES_{i,j(i)}} \cdot 100\,\%$	

Table II.2. Maturity stage calculation

II.4 Model Evaluation Methodology

Helgesson et al. (2012) suggest three maturity model evaluation types. Type 1 (evaluation by the authors) and type 2 (evaluation by practitioners) were already conducted during the development of the DPMM 4.0. So far, the application in business practice, which represents type 3 in the evaluation process, is still missing (Helgesson et al., 2012). The main purpose is both to improve and to demonstrate the applicability of the model. For this step, Helgesson et al. (2012, p. 437) recommend "[...] analyzing the effect on one organization in a case study". While other method approaches are possible, case studies are most frequently used (Wendler, 2012).

Yin (2003, p. 18) defines a case study as an "[...] empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". Case studies differ from other research methods in their (1) particularity, (2) complexity and (3) real-time circumstances (Stake, 1995; Yin, 2003).

Before conducting a case study, a research question must be formulated, which reads in this paper: How can the DPMM 4.0 be used in business practice and identify potentials for improving the degree of digitization in outbound logistics? This question determines the design of the case study with regards to the following four factors: (1) subject, (2) purpose, (3) approach, and (4) process (Thomas, 2011). Table II.3 shows the classification of our case study according to these factors. For our purpose, we use it as a supportive tool for testing the applicability of the DPMM 4.0.

(1) Subject	Key case
(2) Purpose	Instrumental
(3) Approach	Testing a theory / maturity model (DPMM 4.0)
(4) Process	Single case study with two embedded units

Table II.3. Case study design

The company was selected for two reasons: (1) the company's corporate strategy and (2) already implemented Industry 4.0 projects as an indicator of digitization experience. The participating company is a leading multinational manufacturer of electric equipment with more than 300.000 employees. Multiple Industry 4.0 initiatives have been successfully implemented and documented on the "Plattform Industrie 4.0" website (https://www.plattform-i40.de/). The company considers itself as one of the most digitized organizations in the industry. Therefore, we are confident that there is sufficient Industry 4.0 knowledge to contribute to this case study. As part of the corporate strategy the company is continuously looking for opportunities to take advantage of the possibilities of digitization. Therefore, it sought to apply the DPMM 4.0.

The authors decided to evaluate two heterogeneous delivery processes of the multinational manufacturer, which can be interpreted as two subcases. Both factories produce the majority of their products on the basis of a make-to-order production strategy. Factory A is located in Germany with approximately 2,000 employees. The factory generates annual sales between 500 million and one billion euros. Factory B is situated in the United States, employs about 500 people, and generates annual sales between 100 and 250 million euros.

Respondents, as the main source of information, were expected to have sufficient knowledge of both Industry 4.0 and the delivery process. It proved difficult to meet this requirement, but in the end an employee was found who was well enough qualified to carry out the assessment. The participating manager has been dealing with the Industry 4.0 concept for around two years and was able provide in-depth information on the delivery processes in both plants.

In February 2018, the corresponding author visited the manager in the German plant. To reduce subjectivity and in an attempt to triangulate the data, the outbound logistical processes were jointly inspected before the actual assessment. During the plant tour, the modular structure of DPMM 4.0 was introduced, which proved to be straightforward, as the manager was already aware of and familiar with the SCOR framework.

The participating manager named twelve relevant process elements that were consistent with the insights gained during the factory tour: sD2.1, sD2.2, sD2.3, sD2.5, sD2.6, sD2.7, sD2.8, sD2.9, sD2.10, sD2.11, sD2.12, and sD2.15. Factory B was not visited, but due to the plausible and verifiable assessment of plant A, we are confident that the information provided also reflects reality. According to the manager, customers require an Ex Works (EXW) Incoterm. Therefore, plant B does not build efficient loads (sD2.5), route shipments (sD2.6), select carriers (sD2.7), and ship the product (sD2.12). Moreover, packing (sD2.10) has been outsourced to a third party service provider. Overall, sD2.1, sD2.2, sD2.3, sD2.8, sD2.9, sD2.11, and sD2.15 were considered relevant.

The manager then carried out the assessment for both factories. He went through the statements of each relevant element and evaluated them using the predefined Likert scale. During the assessment, he explained why he chose an answer option. Finally, we asked the respondent about the suitability of the model and possible implementation barriers. The results of the maturity model's assessment are presented in the next paragraph.

II.5 Results of the DPMM 4.0 Application With a Multinational Manufacturer

Upon completion of the questionnaire, the maturity scores and stages were determined according to the formulas described in chapter 3. The results were then evaluated and interpreted by the authors. Table II.4 summarizes the individual maturity scores for both factories neglecting the one that do not take place in the factories.

	Results factory A	Results factory B
TRPS	**Stage 2 (29.1 %)**	**Stage 1 (19.8 %)**
RDS "Order processing"	**Stage 2 (31.7 %)**	**Stage 2 (23.3 %)**
sD2.1	Stage 1 (12.5 %)	Stage 1 (12.5 %)
sD2.2	Stage 2 (30.9 %)	Stage 1 (19.0 %)
sD2.3	Stage 2 (26.7 %)	Stage 2 (23.3 %)
sD2.15	Stage 3 (58.3 %)	Stage 3 (41.7 %)
RDS "Warehousing"	**Stage 1 (19.8 %)**	**Stage 1 (14.5 %)**
sD2.8	Stage 2 (20.5 %)	Stage 1 (12.8 %)
sD2.9	Stage 1 (20.0 %)	Stage 1 (16.7 %)
sD2.10	Stage 1 (19.0 %)	-
RDS "Shipping"	**Stage 2 (33.3 %)**	**Stage 1 (18.2 %)**
sD2.5	Stage 2 (35.7 %)	-
sD2.6	Stage 1 (16.7 %)	-
sD2.7	Stage 2 (36.7 %)	-
sD2.11	Stage 3 (42.4 %)	Stage 1 (18.2 %)
sD2.12	Stage 2 (33.3 %)	-

Table II.4. Assessment results for both factories regarding their delivery processes

In general, the delivery process in factory A is more mature than in factory B. No process element scores higher in factory B than in factory A and thus confirms the heterogeneity of the processes. However, the assessment revealed great potential for improvement in factory A. The most digitized process element is "invoice" (sD2.15) for both sites. The least digitized element is the "inquiry and quote" (sD2.1). The tabular results can be visualized, which is particularly useful in practice. Radar charts are used for this purpose (see Figure II.3).

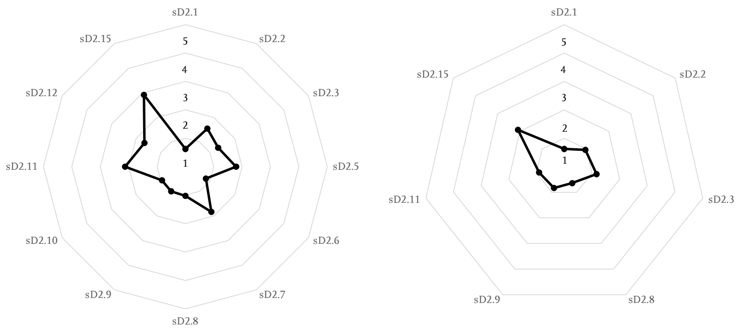

Figure II.3. Radar chart for factories A (left) and B (right)

Figure II.4 helps decision-makers to see at first glance how their factories compare with respect to the process elements present at both sites. The reasons for the differences were discussed in the accompanying interview. The manager provided two possible explanations: Whereas performance measurement in plant B focuses on order lead and production lead times, factory A regards customer satisfaction as the most important key performance indicator. This may have served as an incentive to perform well in the customer-bound delivery process. Moreover, as already mentioned, the two factories work on different Incoterms. This leads to different perceptions of relevance within the factories and is reflected by the assessment results.

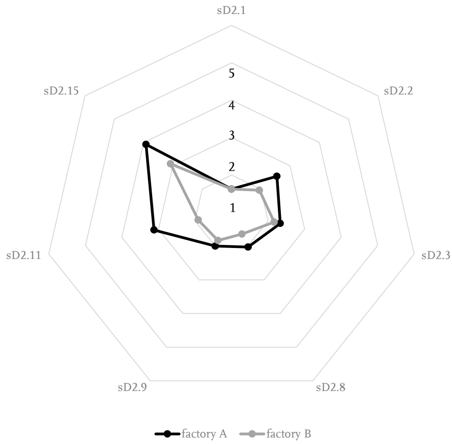

Figure II.4. Radar chart for internal benchmarking of both factories

When deriving a development path, it is recommended to concentrate on the process elements with the lowest scores, which in turn have the greatest digitization deficits. To derive appropriate measures for closing existing gaps within the process elements, the next level of maturity used. Thus, factory A should improve the two process elements with the lowest relative scores, sD2.1 and sD2.6 followed by sD2.8, sD2.9 and sD2.10. Table II.5 outlines suitable measures for the process elements mentioned.

Process element to be improved	Recommended measures
sD2.1 Process inquiry and quote	• Automated receipt of customer inquiries / request for quotes and manual data correction in case of failure • Recourse to carrier data and experience for inquiries / request for quote • Automated response to customer about inquiries / request for quote
sD2.6 Route shipments	• Automated planning of routes • Recourse to carrier information for route planning • Automated comparison of data, decision-making concerning route planning and response to customer about most favorable route • Manual analysis in case of any failure and learning process from solved cases of failure
sD2.8 Receive product from source or make	• Automated planning of picking waves • Automated rescheduling of picking waves in case of short-term changes (e.g., carrier delay) • Automated product reception by autonomously acting transportation system • Automated intelligent product arrangement in warehouse and optimization of warehouse space for an optimized material flow • Product surveillance in the warehouse through sensors and notification when product reaches critical level • Automated recording of product location • Access to sD2.8 information through mobile devices

Process element to be improved	Recommended measures
sD2.9 Pick product	• Automated retrieval of the required order and determination of inventory availability • Automated planning of picking waves • Automated rescheduling of picking waves in case of short-term changes (e.g., carrier delay) • Product collection by picker supported through wearables (especially glasses) • Manual analysis in case of any failure and learning process from solved cases of failure
sD2.10 Pack product	• Automated sorting and combing of products to efficient bundles • Automated configuration of an efficient and resource-saving packaging / package units • Recourse to carrier information for product packaging and efficient bundles • Manual recombining of bundles or rescheduling of picking waves in case of short-term changes (e.g., carrier delay) • Manual analysis in case of any failure and learning process from solved cases of failure

Table II.5. Recommended measures for factory A

Accordingly, factory B is recommended to focus on the process elements sD2.1, sD2.8, and sD2.9. However, priority should be given to elements sD2.2 and sD2.11, which have slightly higher scores. Because factory A has reached higher stages at the process elements sD2.2, sD2.8, and sD2.11, it can serve as a role model and guide the transformation process. In particular, process element sD2.11, which records the highest absolute difference of all values, would benefit from such an exchange between the factories. Besides, since both factories perform poorly in the elements sD2.1 and sD2.9, it might be useful to improve the process together. Table II.6 summarizes the measures for improving the respective process elements.

Process element to be improved	**Recommended measures**
sD2.1 Process inquiry and quote	See Table II.5
sD2.2 Receive, enter, configure and validate order	• Recourse to business partner information for order confirmation • Verification of orderable configuration and calculation of accurate price • Automated check of customer's credit • Automated message to inform the customer and responsible parties about decision on approval or rejection by product modifications • Access for business partner to order data and product traceability
sD2.8 Receive product from source or make	• Planning of picking waves in company's enterprise system by storekeeper • Product verification by storekeeper supported through wearables, especially glasses • Transmission of relevant product data via RFID transponder • Intelligent product arrangement in warehouse and optimization of warehouse space with an optimized material flow by storekeeper supported through wearables, especially glasses • Product surveillance in the warehouse through 360° camera • Recording of product location in company's enterprise system by storekeeper
sD2.9 Pick product	See Table II.5

Process element to be improved	Recommended measures
sD2.11 Load product & generate shipping docs	• Automated planning of outbound logistics and rescheduling in case of short-term changes (e.g., carrier delay) • Manual transmission of product data and accompanying documents via Barcode • Manual planning of product loading onto transportation mode and of necessary loading equipment • Integration of carrier into the safety concept • Manual analysis in case of any failure and learning process from solved cases of failure

Table II.6. Recommended measures for factory B

Overall, the measures derived indicate that the degree of automation must be increased in both plants. In addition, data and information flows, especially between factory and business partners, need to be automated to get closer to Industry 4.0 process excellence. Automated data and error analysis is required to enable machine learning as the next step. The measures listed in Table II.5 and Table II.6 can be interpreted as a short list for process development. It must be ensured that they are in line with both the corporate and the supply chain strategy. The participating manager ensured that this would be the case for all proposed measures. Before a suggested measure is selected and implemented, company-specific cost-benefit analyses must be carried out. To achieve this, quotes must be sought and compared with potential benefits such as a faster, more reliable, cheaper delivery.

Furthermore, the participating manager was asked for suggestions to improve the DPMM 4.0, especially for practicability. He particularly praised comprehensiveness and the customizability of the assessment. Within a short time, detailed and complete results were achieved for both factories. Evaluation results corresponded to the company's perception about its current Industry 4.0 capabilities with regards to the delivery process. The manager stressed that it would be desirable to have additional external benchmarks of companies in the same industry and with a similar number of employees to get feedback on the company's relative position in the market.

Despite the positive feedback, the participating manager stressed the importance of shedding light on some potential blind spots of the assessment due to the adaptability. He referred to factory B which is currently working on an EXW policy. For this reason, several shipping process elements were omitted during the assessment (see Table II.4). However, the corresponding process steps continue to take place – not at the evaluated sites but with the respective external service providers. It is therefore necessary to evaluate these steps in collaboration with the supply chain partners. When a company works with multiple service providers, it is unrealistic to collect data from everyone. In these cases, exemplary service providers should be selected to conduct the assessment.

II.6 Implications and Outlook

This paper presents a case study at two sites of one of the world's leading electric equipment manufacturers to complete the development process of the DPMM 4.0 as proposed by de Bruin et al. (2005). While such validation step is required with regards to a methodologically rigorous development process it also provides theoretical and managerial implications.

First, this research contributes to a more detailed understanding of the current digitization efforts in business practice. With a focus on outbound logistics it adds a complementary perspective to the often investigated manufacturing process (e.g., Leyh et al., 2016; Katsma et al., 2011). This is important as manufacturing processes are by no means the only supply chain processes to be digitized. Second, this work also contributes to the available logistics maturity models (e.g., Battista et al., 2012). The existing models do not account for the current digitization trends and are therefore of little use for decision-makers, who want to prepare for the digital age ahead. Third, this work adds to the emerging literature of cyber-physical logistics systems (CPLS). The final DPMM 4.0 maturity stage describes a process that is fully transparent to all actors involved with embedded, linked IT-systems that autonomously act and interact with the environment, which reflect the concept of CPLS. So far, CPLS have only been described (e.g., Pujo & Ounnar, 2018), whereas our paper provides an example as of how to improve towards a state of excellence.

With regards to business practice, this work provides managers with valuable insights into how to approach the digitization of outbound logistics, which is particularly relevant as it involves direct customer contact. Such effort would most certainly not be too late as the case study reveals low digitization levels with regards to outbound logistics, although the company sees itself as one the most digitized companies in the industry. Our results indicate that logistics processes could become a critical bottleneck on the path towards a connected and smart supply chain. Decision-makers who want to evolve their supply chains should therefore take a more balanced approach and not just focus on manufacturing.

A major limitation of this paper is that the model has only been applied to two factories of one company. Nevertheless, it appears applicable to other enterprises because of the high flexibility of the model's architecture and the positive feedback received during the case study. Moreover, the data within the case came from a single source within the company and the corresponding author's visit at the assessed production sites. In terms of data triangulation (Denzin, 2006), it would have been desirable to further increase the number of sources (time, space, and person). However, the number of persons with sufficient expertise concerning the digitization of the logistics processes is limited. This applies in particular to large companies with highly specialized job profiles. For these reasons, we call for future investigations to replicate our findings with other companies (e.g., different company size, different industry) and multiple data sources. Against this background, studies using a mixed-method approach also appear promising.

While this case study concludes the model development, it is by no means the end of the project. We are currently working on an online DPMM 4.0 assessment tool to collect data about the actual status quo of digitization in outbound logistics. These data may serve as reference points for external benchmarks and give companies a quick first impression of how they compare. The successful model application can also motivate the development of other process-based maturity models, for example for the sourcing process, which is necessary to fully realize the vision of a seamless, transparent, and efficient value creation network that remains competitive in the digital age.

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Article III. Quo Vadis, Business Process Maturity Model? Learning from the Past to Envision the Future

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Abstract. To support companies in systematically improving their business processes, academia has developed and published various business process maturity models in recent decades. Tarhan et al. (2016) expressed initial doubts about the quality of many of the models in their literature review. This paper extends their review by five years (2015–2019) and additionally analyzes the publication outlets as an indicator of model quality. The results strongly provide that business process maturity models are mainly released in less-recognized journals. A reason for this might be problems with replicability and relevance, which are the main criteria for acceptance in higher-quality journals. This finding motivated the derivation of literature-based criteria to increase the transparency, the replicability, and the content relevance of these models. These criteria are a first step to support researchers in publishing more transparent and replicable business process maturity models and to guide reviewers when evaluating papers that are considered for publication. In addition, practitioners benefit from more useful and accessible models.

Keywords. Business Process · Business Process Management · Maturity Model · Systematic Literature Review · Publication Outlets · Transparency · Replicability

III.1 Introduction

To be able to compete in today's environment with permanent competitive pressure, more complex value chains, and economic uncertainty, a continuous improvement of the underlying business processes is necessary. Business process maturity models (BPMMs) are regarded as an essential instrument (Kalinowski, 2018) when determining the organization's status, deriving improvement measures, and conducting cross-company comparisons (Felch et al., 2019). Thus, these models offer a structured approach to initiate and support short-term operational projects as well as facilitate long-term strategic changes (Felch et al., 2019). As a response to practical interest, a steady increase in publications can be observed over recent decades (Pöppelbuß & Röglinger, 2011; Rosemann, 2015). Pöppelbuß and Röglinger (2011, p. 1) were the first to reflect critically on this and therefore questioned "[...] whether high quantity goes along with high quality". Tarhan et al. (2016) conducted a systematic review of the literature published between 1990 and 2014. In line with Pöppelbuß and Röglinger (2011) observation, one of their findings was initial doubt about the quality and usefulness of some reviewed BPMMs. Since then, five years have passed. Therefore, this paper complements the previous review with a detailed search for and analysis of recent BPMM developments. Accordingly, the first research question is:

(1) Considering the most recent BPMM publications, how has the state of research regarding BPMMs changed in the last five years?

The results indicate only minor changes in the research area. To further investigate whether a critical perspective on the quality of some BPMMs may be justified, we additionally address the following research question:

(2) How well recognized are the publication outlets of BPMM articles?

The findings indicate that the papers are mainly published in less-recognized journals. This can be attributed to a low reproducibility of the design/concept and method as well as little relevance to theory and practice, which are fundamental requirements for publication in highly ranked journals (Bornmann et al., 2008). To improve on these issues, we posit a third research question:

(3) Which criteria should authors consider when publishing BPMMs?

The study at hand contributes to existing knowledge (1) by guiding researchers in implementing greater transparency and thus creating a solid and substantiated BPMM and (2) by providing reviewers with a detailed checklist to rely on when evaluating submitted models in the future, which will also lead to more applicable models in practice.

The remainder of the article is structured as follows: The next chapter describes the approach and the results of the extended literature review. In addition, the publication outlets of all journal publications are analyzed. Subsequently, criteria for publishing transparent and replicable BPMMs are first derived and then applied to five recently released models. This research concludes with a summary of the key results, theoretical and managerial implications, and the description of further research opportunities.

III.2 The Status Quo in BPMM Research

In the past, several literature reviews of BPMMs have been conducted, e.g., van Looy et al. (2010) or Wendler (2012). The most comprehensive review was published by Tarhan et al. (2016); their review focuses on challenges in the field of BPMM and tries to stimulate further research. The review is conducted in a general "all-inclusive manner" with no specific focus on a certain domain or aspect of business process management (BPM). They examined studies that were published between 1990 and 2014 in academic journals, conference proceedings, and books. Overall, 61 studies out of 2,899 references were selected for further analysis. In line with Wendler (2012), they state that the majority of publications involved the development of a BPMM, the application of a model, or a comparison between models. A key finding is the lack of empirical research on model development. In addition, Tarhan et al. (2016) call for more prescriptive rather than descriptive models to provide more guidance for organizations to progress to the next maturity level. They stress that a major prerequisite for a model to fulfill its prescriptive purpose is comprehensive documentation. Most notably, the authors report that only a few studies examine the relationship between BPMMs and improved business performance. Therefore, they conclude: "[...] 4 out of 9 leading maturity models have not been subjected to an empirical validation reported in the existing literature at all [...]. These numbers indicate that there is very limited empirical evidence on [...] the usefulness of the maturity models." (Tarhan et al., 2016, p. 128).

III.2.1 Review of Recently Published BPMM Research

Because Tarhan et al. (2016) review process ended in 2014, this paper extends the previous search with a detailed analysis of the latest BPMM developments (2015–2019). The original search (OS) adopted search terms and databases from Tarhan et al. (2016) and is complemented by a forward (FS) and backward search (BS). Initially, 5,221 references (OS: 2,744; FS: 489; BS: 1,988) were retrieved, with 69 of those (OS: 49; FS: 16; BS: 4) considered relevant for further analysis. Combined with the 61 articles that have been identified by Tarhan et al. (2016), these findings indicate that in almost 30 years, 130 articles have been published in the field of BPMM. Moreover, the publication rate has increased considerably in recent years (see Figure III.1), and the publication type has changed. While the majority of studies used to be published in conference proceedings (journals: 25; conferences: 29; books: 7), in the last five years, articles are more frequently published in journals (journals: 39; conferences: 30; books: 0).

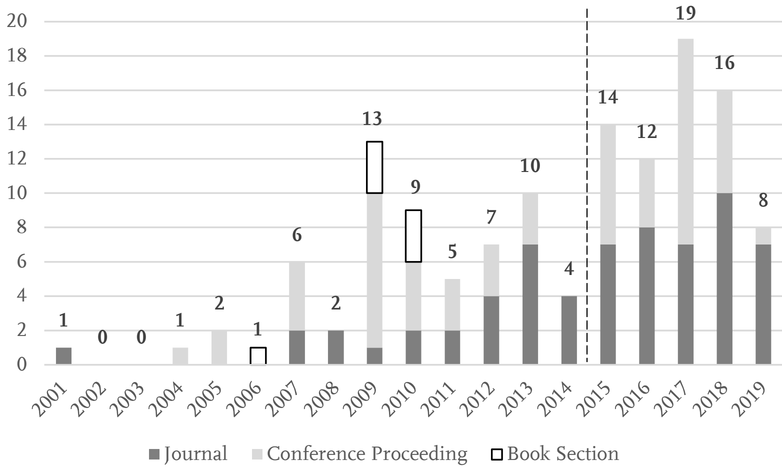

Figure III.1. Distribution of articles by year

A more detailed analysis shows that McCormack and Johnson (2001)'s maturity model (BPO-MM) (27 studies), Rosemann and de Bruin (2005)'s model (BPM-CF) (24), and Object Management Group (2008)'s BPMM (BPMM-OMG) (23) are the ones most frequently referred to in the literature. These three models, along with the Capability Maturity Model Integration (CMMI) (Software Engineering Institute [SEI]), reveal the strongest increase in publications between 2015 and 2019. Moreover, the BPO-MM, BPM-CF, and BPMM-OMG are the most commonly used models to examine the relationship between BPMMs and improved business performance (1990–2014: 7; 2015–2019: 7).

Nevertheless, the total number of those articles remains low. Tarhan et al. (2016) reported a set of nine ‘leading’ maturity models based on the recognition that the models received in academia. Based on the findings of this complementary review, we suggest adding another three to the list of ‘leading’ models – the CMMI, the Process Performance Index (PPI) (Rummler-Brache Group), and the Business Process Maturity (BPM-MC) (McCormack, 2007). To analyze the most recent research streams, all articles were classified in terms of content and focus in accordance with the procedure used by Tarhan et al. (2016) (see Appendix A). The subcategories ‘description’ (20), ‘empirical study on application/validation’ (24/22), and ‘theoretical analysis’ (21) show the strongest increase (see Figure III.2).

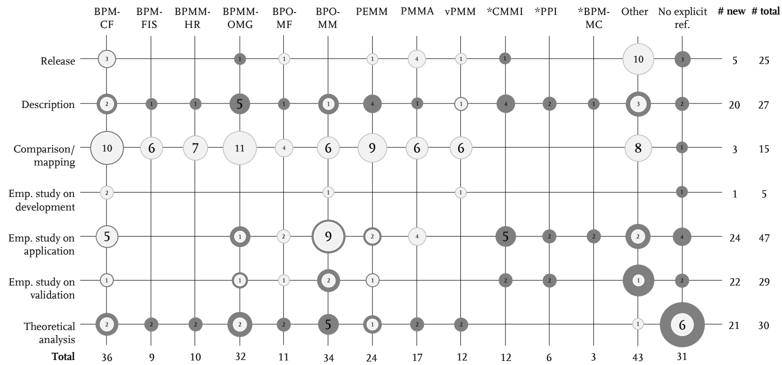

Figure III.2. Number of articles per BPMM by research content[16]

The number of studies presenting a developed model (‘release’) clearly decreased (5). The call for more empirical research on the development of maturity models has not yet been accounted for. The subcategory ‘meta-analysis’ replaces ‘development’ as the one with the most published studies (see Figure III.3). The other three subcategories, in particular ‘meta-analysis’ (23), have experienced strong growth.

[16] Note: An article may have multiple research contents and may address multiple BPMMs.

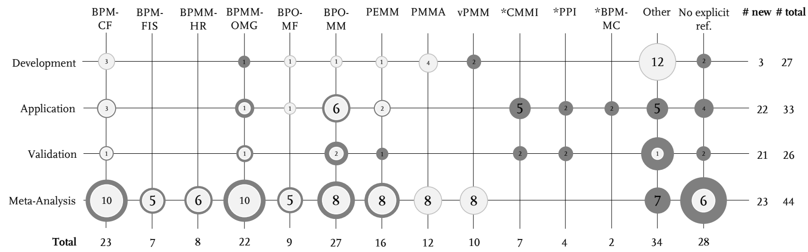

Figure III.3. Numeric distribution of articles per BPMM by main research focus[17]

Returning to Tarhan et al. (2016) hypotheses, it can be stated that hardly anything has changed in the area of BPMMs (see Table III.1). H2 and H3 remain valid, whereas minor progress has been made concerning H1 and H4. It appears that most of Tarhan et al. (2016) recommendations, e.g., refining the prescriptive features of existing BPMMs, have been neglected to date, which leads us to the conclusion that the initial doubts about the quality of BPMMs remain valid. To substantiate this hypothesis, we extend the literature analysis by examining the publication outlets of the individual articles in the following paragraph. Highly ranked journals are known to pay particular attention to scientific standards, so it should be difficult to publish articles with qualitative weaknesses in such outlets. Thus, if the assumption of lower quality is substantiated, this should be reflected in the publication outlets.

[17] Note: An article may address multiple BPMMs.

Hypothesis by Tarhan et al. (2016)	Results (2016, p. 129)	Results (2020)
H1: The BPM academic community has put more effort and emphasis on developing maturity models than empirically evaluating them.	Around one-third of the studies introduce a BPMM (20 models in 61 studies). Only 2 out of 9 leading models are referred to by studies that involve empirical works on their development, application, and validation.	Around 7 % of the studies introduce a BPMM (5 models in 69 studies). None of the three leading models have been used in empirical works on the development, application, and validation of BPMMs.
H2: There is a lack of studies validating that an increased process maturity level of an organization with respect to a BPMM leads to an improved business performance.	Only 7 out of 61 studies confirm that an increased process maturity level leads to an improved business performance.	Only 7 out of 69 studies confirm that an increased process maturity level leads to an improved business performance.
H3: Most BPMMs display descriptive rather than prescriptive characteristics.	The majority of the proposed models possess descriptive properties and show limited prescriptive features.	The three leading models possess mainly descriptive properties and have limited prescriptive features.
H4: The distinction between a maturity model and an assessment model is not well defined in the BPMM research.	Only 2 out of 9 leading models make a distinction between the maturity model and the assessment model.	2 out of 3 leading models make a distinction between the maturity model and the assessment model.

Table III.1. Summary of the findings regarding the hypotheses proposed by Tarhan et al. (2016)

III.2.2 Publication Outlets of BPMM Research

From a BPMM author's perspective, the journal's level of recognition plays a decisive role, as it impacts the highest possible model application and dissemination rate. Consequently, authors will try to publish their models in the most highly recognized journals. Over the years, there has been a growing interest in creating systematic and objective evaluation methods to determine the quality of a journal. Several researchers, including Garfield (1972) and Hirsch (2005), have proposed so-called impact factors. In general, the higher the impact factor is, the higher the ranking of the journal and thus the reputation of the published paper. Accordingly, we analyze the publication outlets of the 64 articles that have been published in academic journals (1990–2019). This accounts for 49% of all 130 reviewed publications. To determine the value of the publications, three impact factors are used: (1) the index by Thomson Reuters (Reuters Index) (Web of Science Group), (2) the H Index by Hirsch (2005), and (3) the SCImago Journal Rank (SJR) indicator (SJR - SCImago Journal & Country Rank). The impact factors are based on data from SJR – SCImago Journal & Country Rank (www.scimagojr.com, as of January 2020).

Unlisted journals, such as "Computer and Information Science", are rated with an impact factor of 0. Beyond that, the mean values of each impact factor are calculated (see Table III.2). Considering all publications (1990–2019), the average Reuters Index is 2.4, the average H Index is 43.6, and the average SJR index is 0.5. Furthermore, the analysis is extended to several subcategories that are related to model development and application in general. When comparing the means, the values from the 2015–2019 publications are mostly below those of the 1990–2014 publications. Herein, the subcategories 'release', 'empirical study on application', and 'application' show the greatest differences between the periods.

Article classification	Period	# Articles	Reuters Index	H Index	SJR
Release	1990–2014	6	3.9	59.8	0.4
	2015–2019	4	2.1	27.5	0.5
	1990–2019	*10*	*3.2*	*46.9*	*0.5*
Description	1990–2014	4	1.2	33.3	0.3
	2015–2019	11	2.5	43.3	0.8
	1990–2019	*15*	*2.2*	*40.6*	*0.6*
Empirical study on application	1990–2014	10	3.8	60.3	0.9
	2015–2019	11	1.3	20.6	0.3
	1990–2019	*21*	*2.5*	*39.5*	*0.6*
Development	1990–2014	9	2.9	51.3	0.4
	2015–2019	3	2.8	36.7	0.7
	1990–2019	*12*	*2.9*	*47.7*	*0.4*
Application	1990–2014	6	5.2	83.0	1.2
	2015–2019	10	1.4	20.8	0.3
	1990–2019	*16*	*2.8*	*44.1*	*0.6*
Total	1990–2014	25	3.4	61.8	0.7
	2015–2019	39	1.8	31.9	0.4
	1990–2019	*64*	*2.4*	*43.6*	*0.5*

Note: The mean values include the impact factors of publications from FS and BS. Since Tarhan et al. did not perform any FS or BS, we also analyzed the mean values without articles found in the FS and BS, which revealed only minor differences and did not affect the conclusions.

Table III.2. Impact factors of BPMM research

To assess the influence and relevance of the journals, the mean values (1990–2019) are compared with the average impact factor of selected overarching subject categories of the journals. For that purpose, the top 50 journals were identified using the SJR website to calculate their average impact factor (see Table III.3).

Subject category according to SJR	Reuters Index	H Index	SJR
Range incl. all subject categories	{0;206.9}	{0;1096}	{0.1;72.6}
Range incl. 12 selected subject categories	{0;19.4}	{0;335}	{0.1;30.5}
Business and International Management	5.3	103.1	3.1
Business, Management and Accounting (misc.)	3.7	84.5	1.9
Computer Science Applications	7.4	144.6	2.6
Economics and Econometrics	5.6	137.2	7.4
Industrial and Manufacturing Engineering	5.2	101.8	1.8
Information Systems	6.0	93.3	1.8
Information Systems and Management	3.5	57.9	1.1
Management Information Systems	2.8	47.4	1.0
Management of Technology and Innovation	4.7	98.4	2.5
Management Science and Operations Research	3.7	85.2	1.8
Software	6.8	124.3	2.2
Strategy and Management	5.6	123.7	3.5
Ø Subject categories	5.0	100.1	2.6

Table III.3. Impact factors of the top 50 journals in selected subject categories

It is striking that for the period from 1990–2019, the highest values of the considered article categories (see Table III.2; Reuters Index: 3.2 for 'release' publications, H Index: 47.7 for 'development' publications, SJR: 0.6 for multiple categories) only reach the lowest mean values of the selected subject categories (see Table III.3; Reuters Index: 2.8, H Index: 47.4, SJR: 1.0 in each case for 'Management Information Systems') and are well below their average values (Ø subject categories, as shown in Table III.3). To better understand the significance of the individual values, Table III.3 also lists the lowest and highest values of each index across all subject categories and across the selected overarching subject categories. Although it must be acknowledged that impact factors change over time, the comparison provides a strong indication that articles about BPMMs are published in less-recognized journals, which are of minor relevance in the scientific community. This finding is supported by van Looy (2014, p. 18), who notes that "[...] the many existing BPMMs are assumed to differ in quality". Reasons for this might be an insufficient theoretical foundation and methodology as well as unsatisfactory model documentation; these reasons can lead to a lack of replicability, which seems to be a general problem with maturity models (Albliwi et al., 2014; Becker et al., 2009; de Carolis et al., 2017; Mettler, 2010). Since the replicability of a design/concept and the methodology are key criteria that are regularly used in peer-review processes and by editors when evaluating submissions (Bornmann et al., 2008), these results are hardly surprising. To improve on this issue, researchers need to pay particular attention to transparency, which serves as a strong indicator of the ability to replicate research results (Aguinis et al., 2018; Campbell et al., 2014). Furthermore, to increase the chances of publication, research has to be considered relevant to theory and practice.

Research is considered relevant if it is significant or useful (Cachon et al., 2020). To ensure this for BPMMs, authors should refer to empirically studied cause-effect relationships when defining the model content, especially with respect to the BPM application fields. This addresses our third research question. In an endeavor to provide better guidance for authors, reviewers, and editors, we again review existing literature to identify transparency and content criteria and thus seek to increase not only the quantity but also the quality of publications in the years ahead.

III.3 Transparency and Content Criteria for BPMM Development

To date, only a few publications have contributed to the development and communication of maturity models in general: on the one hand, procedure models, such as those by Becker et al. (2009) or de Bruin et al. (2005), have been published; on the other hand, general design principles by Pöppelbuß and Röglinger (2011) have been released. None of the related work has aimed at deriving transparency and content criteria. Our study represents a first step to address this issue. Against this background, we conducted a literature search in the EBSCO, Google Scholar, ScienceDirect, and Web of Science databases with the search terms 'maturity model', 'capability model', 'design science', 'transparency', 'business process management', 'business process', 'business performance', empiric*', and 'valid*'. It should be noted that our search included only academic literature and excluded publications, such as white papers, expressions of opinions, student papers, PowerPoint presentations, and papers published in nonacademic journals and magazines. After reviewing the titles, abstracts, keywords, content, and removing duplicate studies, a total of 33 relevant articles were identified (Babic-Hodovic et al., 2012; Becker et al., 2009; Bronzo et al., 2013; de Bruin et al., 2005; Diller & Ivens, 2006; Forsberg et al., 1999; Fraser et al., 2002; Gustafsson et al., 2003; Helgesson et al., 2012; Hellström & Eriksson, 2013; Hernaus et al., 2012; Ittner & Larcker, 1997; Kohlbacher & Gruenwald, 2011a, 2011b; Kohlbacher & Reijers, 2013; Kumar et al., 2010; Lahrmann et al., 2010; Leyer et al., 2017; Maier et al., 2012; McCormack, 2001, 2007; McCormack & Johnson, 2001; Mettler, 2010; Milanović Glavan & Bosilj-Vukšić, 2017; Movahedi et al., 2016; Münstermann et al., 2009; Münstermann et al., 2010; Nilsson et al., 2001; Pöppelbuß & Röglinger, 2011; Pradabwong et al., 2017; Škrinjar et al., 2008; Sonnenberg & vom Brocke, 2012; van Steenbergen et al., 2010; Wendler, 2012). The criteria proposed in the publications were highlighted, were then structured according to their intended use, and duplicates were eliminated. Finally, they were grouped according to the three dimensions: (1) methodology, (2) model documentation, and (3) model content scope (see Table III.4 to Table III.6). Although we do not claim that the derived set of criteria is exhaustive, we are confident that it will provide a good starting point for further research and discussion.

III.3.1 Literature-Based Criteria

Methodology: To ensure scientific rigor and to create a theoretically sound model, an appropriate methodology must be adopted in the design and evaluation process. Drawing on existing knowledge, several procedure models, such as de Bruin et al. (2005) and Becker et al. (2009), have been proposed to provide standardized and methodological steps (see Table III.4). For model development, explorative research methods – especially focus groups, case studies, or Delphi studies – are suggested in addition to literature reviews (Becker et al., 2009; de Bruin et al., 2005; Lahrmann et al., 2010; van Steenbergen et al., 2010). Simulations, experiments or qualitative research methods, e.g., expert interviews, can be considered for improving models (Becker et al., 2009; Helgesson et al., 2012; Sonnenberg & vom Brocke, 2012). For model validation, the studies suggest the use of field experiments, surveys, expert interviews, focus groups, and case studies (Mettler, 2010; Sonnenberg & vom Brocke, 2012; Wendler, 2012).

Element	**Criteria for BPMM publication**
Procedure model	E.g., Becker et al. (2009), de Bruin et al. (2005)
Development method	Literature review, case study, Delphi study, focus group
Evaluation method	Demonstration with prototype, experiment with prototype or system, benchmarking, survey, expert interview, focus group
Application method	Case study, field experiment, survey, expert interview, focus group

Table III.4. BPMM criteria for the dimension 'methodology'

Model Documentation: Due to model application and dissemination depending on documentation quality, the provision of a high degree of transparency is important for the respective user groups. Therefore, describing the model's purpose (descriptive, prescriptive, or comparative) is essential (Pöppelbuß & Röglinger, 2011) (see Table III.5). In addition, model components, such as the title and a description for each maturity level, the number of dimensions and elements, and a description for each activity, should be provided (Fraser et al., 2002; Maier et al., 2012; Pöppelbuß & Röglinger, 2011). Depending on the model purpose, additional elements should be published. For descriptive models, the evaluation criteria and methodology should be described, whereas for prescriptive models, improvement measures, decision criteria, and methodology should be highlighted (Pöppelbuß & Röglinger, 2011).

Element	**Criteria for BPMM publication**
Purpose of use	Descriptive, prescriptive, comparative
Basic components	Number of levels, descriptor for each level, generic description of the characteristics of each level, number of dimensions, number of elements for each process area, description of each activity as it might be performed at each maturity level
Components of descriptive maturity models	Intersubjectively verifiable criteria for each maturity level and level of granularity, target group-oriented assessment methodology
Components of prescriptive maturity models	Improvement measures for each maturity level and level of granularity, decision calculus for selecting improvement measures, target group-oriented decision methodology

Table III.5. BPMM criteria for the dimension 'model documentation'

Model Content Scope: To assess the content of the model, we rely on BPM factors, whose influence on business performance has been empirically confirmed by at least two independent studies. This resulted in five relevant constructs: (1) organization, (2) supply chain integration, (3) process, (4) IT, and (5) employees (see Table III.6). 'Organization' addresses the company structure, which is adapted to the process view (e.g., Bronzo et al., 2013, Kohlbacher & Reijers, 2013). Furthermore, the strategic focus determines the alignment of the business processes, whereas the corporate culture is based on teamwork, willingness to change, and a cooperative management style (e.g., Milanović Glavan & Bosilj-Vukšić, 2017, Pradabwong et al., 2017). 'Supply chain integration' addresses the relationships among companies, their suppliers and customers. It is mainly about joint planning, forecasting, and process improvement between suppliers and companies as well as understanding customer needs and increasing their satisfaction (e.g., Bronzo et al., 2013, Milanović Glavan & Bosilj-Vukšić, 2017). The third construct 'process' relates to the coordination and improvement of business processes. In addition to the process view, this includes the determination of process owners (e.g., Ittner & Larcker, 1997, Kohlbacher & Gruenwald, 2011a). The definition and documentation of the essential processes are the starting point for the design, evaluation, and continuous improvement of the processes (e.g., McCormack, 2001, Movahedi et al., 2016, Nilsson et al., 2001, Škrinjar et al., 2008). The construct 'IT' involves the redesign and application of suitable IT systems both within and across companies (e.g., Diller & Ivens, 2006, Pradabwong et al., 2017).

Element	**Criteria for BPMM publication**
Organization	Organizational structure, strategic alignment, culture
Supply chain integration	Supplier orientation, customer orientation
Process	Process focus, process owner, definition and documentation of processes and process measurement, design of processes, measurement of processes, improvement of processes
IT	Support of IT tools
Employees	Design of jobs and workplace, employee development, employee involvement and motivation, employee information exchange

Table III.6. BPMM criteria for the dimension 'content scope'

The construct ‘employees’ addresses the recruitment, commitment, and development of staff (e.g., Bronzo et al., 2013, Ittner & Larcker, 1997, Pradabwong et al., 2017). Moreover, it places emphasis on the interaction and communication between employees and management (e.g., Hernaus et al., 2012, Kumar et al., 2010). These dimensions represent capabilities that have a proven effect on the organization’s performance. Therefore, at least one construct should be thematically addressed by BPMMs.

III.3.2 Evaluation of Recently Published BPMMs

To further emphasize the observation that many BPMM publications show qualitative weaknesses, we assessed the five models that, according to the literature review in Sect. III.2.1, were released between 2015–2019: (1) the MM-AND (Andriani et al., 2018), (2) the MM-BER (Berger et al., 2018), (3) the MM-CHA (Chaghooshi et al., 2016), (4) the MM-FRO (Froger et al., 2019), and (5) the MM-SLI (Sliż, 2018). Using a structured content analysis (Krippendorff, 2019), the coding process was performed using MAXQDA Plus 2018. Each article represents a unit of analysis. Initially, coder A, who developed the criteria, coded the articles based on the codebook. To confirm that the criteria application is not limited to one researcher, a second coder (coder B, who has studied maturity models for years) independently worked on the same five models. Criteria that are not included in the codebook but mentioned in the articles were assigned to the category ‘others’ and analyzed separately. This category was used for the evaluation method of the MM-AND, as informal interviews, secondary documents, and observations were applied in addition to expert interviews. After the coding process, both files were merged, and the coded sections were compared against each other. An “agreement rate” (representing the number of matching recordings divided by the number of all recordings) of 84.03% was achieved. This value falls within the range that is considered reliable (Neuendorf, 2002, p. 143). Before the data were interpreted, all disagreements were discussed until a consensus decision was reached. The detailed results of the analysis can be found in Appendix B. Although procedure models for the creation of maturity models have been publicly available for approximately ten years, only two articles (articles about the MM-BER and the MM-SLI) refer to such procedure models.

When developing models, the authors draw solely on existing literature; other methods are not applied. One article reports an extensive evaluation process using different methods, such as case studies and interviews (MM-AND), whereas the other articles do not even address the evaluation of their models. It remains unclear whether an evaluation took place or whether the evaluation is simply not described. In contrast, validation in practice is reported more frequently (MM-BER, MM-CHA, MM-FRO), mainly using case studies (MM-CHA, MM-FRO). Furthermore, it can be concluded that basic components are usually documented, including the number of maturity levels, the descriptors for each level, and the number of elements for each process area. However, the important criterion 'description of each activity as it might be performed at each maturity level' is not addressed, although this criterion is crucial for both model applicability and dissemination in practice. No article adequately addressed criteria for descriptive models, and criteria for prescriptive purposes are not considered at all. We therefore conclude that the previously described lack of quality (Pöppelbuß & Röglinger, 2011; van Looy, 2014) has not improved in recent years – at least not with regard to the five models under investigation. Two models consider almost all content criteria (the MM-BER and the MM-CHA), whereas the others have room for improvement. The criteria 'strategic alignment' and 'definition and documentation of processes and process measurement', which are incorporated by all five models, are considered to be particularly important. It is striking, however, that 'process focus' and 'design of jobs and workplace' are addressed by only one model each. 'Management of financial resources' and 'management contract' are, for example, elements that are not included in the codebook but mentioned in the maturity models. Our literature search did not identify at least two independent studies that verified the influence of these factors on business performance. Thus, no statement about the relevance of these elements can be made. Furthermore, it can be concluded that in almost all cases, comprehensive documentation that would allow for replicability and self-assessment by companies is not accessible. This reinforces the approach of improving transparency and relevance to achieve greater replicability and to publish BPMMs in higher quality journals.

III.4 Conclusion

This paper provides several theoretical contributions. First, it updates the exhaustive literature review that was conducted by Tarhan et al. (2016). We find that in the past five years, more BPMM articles have been published, but the research gaps originally identified by Tarhan et al. (2016) remain valid. Special focus should be given to contributions that address the impact of BPMMs on business performance. However, empirical studies on the development of maturity models should also be further emphasized. Second, we extended Tarhan et al. (2016) work by analyzing the outlets in which BPMMs were published. We find that BPMM articles of the past three decades have been mainly published in less-recognized journals. We argue that an important reason for this is a lack of methodological rigor and a low level of model documentation, which both limit the model's replicability, a key factor by reviewers in high-quality journals. Third, the study introduces criteria in three dimensions (methodology, model documentation, and content scope) to improve the transparency and relevance of BPMMs. The criteria were assessed using five previously published BPMMs. In particular, the dimension 'methodology' has been strongly neglected. The 'model documentation' and 'model content scope' dimension were addressed better; however, decisive criteria that would allow the application of the model in practice are still missing. The results underpin the need to increase transparency to achieve greater replicability and consequently to publish these models in higher-quality journals that have more relevance and influence on both the scientific community and practice.

Our proposed criteria constitute a first step towards overcoming this challenge but do not represent an exhaustive list of criteria that must be followed. Instead, these criteria are a starting point towards better BPMMs that can provide some orientation. The criteria can be valuable for (1) supporting academia in the publication of scientifically sound and transparent work on BPMMs and (2) providing reviewers with a detailed checklist to rely on when evaluating submitted models in the future. In addition, decision makers in companies can also benefit from well-founded and more transparent BPMMs. Thus, more efficient model selection and application can be ensured. Moreover, this study is a good starting point for decision makers who are thinking about applying a maturity model to improve business processes. By extending the literature review (2015–2019), practitioners obtain an overview of which current and 'leading' BPMMs are suitable for each area and where limitations exist. Finally, the extended overview enables researchers to build on the identified research gaps. A limitation of the paper is that the criteria are based solely on the literature. To confirm the criteria's usefulness, a long-term study would have to be conducted. Furthermore, the criteria have only been tested on a small number of models. An application to other maturity models should be considered. In addition to the lack of quality, there may be other reasons for not publishing BPMMs in higher quality journals. Further investigations are needed, such as examining the reviews of BPMM papers that are submitted to highly-ranked journals. Despite the limitations mentioned herein, we believe that such research helps to improve BPMMs, which is warranted to further support the continuous improvement of business processes in times of increasing competitive and economic pressure.

III.5 Appendix A. Categorization of the Studies

Due to page restrictions, the complete list of the 69 references for the supplementary systematic literature analysis (2015–2019) (see Digital Appendix A) and their categorization of the studies (see Digital Appendix B) can be found in the supplementary material.

Digital Appendix A. Complete List of 69 Studies (2015–2019)

No	Reference of articles (2015–2019)
A1	AlShathry, O. (2016). Business Process Management: A Maturity Assessment of Saudi Arabian Organizations. *Business Process Management Journal, 22*(3), 507–521.
A2	Andriani, M., Samadhi, T. A., Siswanto, J., & Suryadi, K. (2018). Aligning Business Process Maturity Level with SMEs Growth in Indonesian Fashion Industry. *International Journal of Organizational Analysis, 26*(4), 709–727.
A3	Brzychczy, E., & Kostka, D. (2018). Assessing Process Maturity of an Underground Mine: A Case Study. *Journal of the Polish Mineral Engineering Society*, 55–63.
A4	Chaghooshi, A. J., Moradi-Moghadam, M., & Etezadi, S. (2016). Ranking Business Processes Maturity by Modified Rembrandt Technique with Considering CMMI Dimensions. *Iranian Journal of Management Studies, 9*(3), 559–578.
A5	Christiansson, M.-T., & van Looy, A. (2017). Elements for Tailoring a BPM Maturity Model to Simplify its Use. In J. Carmona, G. Engels, & A. Kumar (Eds.), *Lecture Notes in Business Information Processing, Business Process Management Forum* (pp. 3–18). Springer.
A6	de Waal, B. M. E., Joku, S., & Ravesteijn, P. (2017). Do Differences between Managers and Employees Matter? A Case Study on BPM Maturity and Process Performance. In *Proceedings of the 5th International Conference on Management, Leadership and Governance,* Johannesburg, South Africa.
A7	de Waal, B. M. E., Valladares, R., & Ravesteijn, P. (2017). BPM Maturity and Process Performance: The Case of the Peruvian Air Force. In *Proceedings of the 23rd Americas Conference on Information Systems,* Boston, United States of America.

No	Reference of articles (2015–2019)
A8	Dewi, L. P., Wibowo, A., & Leander, A. (2015). Business Process Maturity at Agricultural Commodities Company. In R. Intan, C.-H. Chi, H. N. Palit, & L. W. Santoso (Eds.), *Communications in Computer and Information Science, Intelligence in the Era of Big Data* (pp. 505–513). Springer.
A9	Dijkman, R. M., Lammers, S. V., & de Jong, A. (2015). Properties that Influence Business Process Management Maturity and its Effect on Organizational Performance. *Information Systems Frontiers, 18*(4), 717–734.
A10	Exalto-Sijbrands, M., Maris, A., & Ravesteijn, P. (2016). The Influence of Business Process Maturity on Managerial Behaviour: A Web Shop Supply Chain Case Study. In *Proceedings of the 4th International Conference on Management Leadership and Governance,* St. Petersburg, Russia.
A11	Froger, M., Bénaben, F., Truptil, S., & Boissel-Dallier, N. (2019). A Nonlinear Business Process Management Maturity Framework to Apprehend Future Challenges. *International Journal of Information Management, 49,* 290–300.
A12	Gabryelczyk, R. (2016). Does Grade Level Matter for the Assessment of Business Process Management Maturity? *Our Economy, 62*(2), 3–11.
A13	Gabryelczyk, R. (2019). Exploring BPM Adoption Factors: Insights into Literature and Experts Knowledge. In E. Ziemba (Ed.), *Lecture Notes in Business Information Processing, Information Technology for Management: Emerging Research and Applications* (pp. 155–175). Springer.
A14	Hrabala, M., Opletalova, M., & Tucekc, D. (2017). Business Process Management in Czech Higher Education. *Journal of Applied Engineering Science, 15*(1), 35–44.
A15	Janssen, K. J., Nendels, F. C. W., Smit, S. L., & Ravesteijn, P. (2015). Business Processes Management in the Netherlands and Portugal: The Effect of BPM Maturity on BPM Performance. *Journal of International Technology and Information Management, 24*(1), 33–52.
A16	Jurczuk, A. (2017). Business Process Inconsistencies in Polish Small and Medium Enterprises. In *Proceedings of the 23rd International Scientific Conference on Economic and Social Development,* Madrid, Spain.
A17	Kahrovic, E., & Vignjevic-Djordjevic, N. (2019). The Five Stages of Business Process Management Maturity Model. *MEST Journal, 7*(2), 49–54.
A18	Kalinowski, T. B. (2016). Analysis of Business Process Maturity and Organisational Performance Relations. *Management, 20*(2), 87–101.

No	Reference of articles (2015–2019)
A19	Lee, D., Gu, J.-W., & Jung, H.-W. (2019). Process Maturity Models: Classification by Application Sectors and Validities Studies. *Journal of Software: Evolution and Process, 31*(4), 1-30.
A20	Lima, E. S., Viegas, R. A., & Costa, A. P. C. S. (2017). A Multicriteria Method Based Approach to the BPMM Selection Problem. In *Proceedings of the International Conference on Systems, Man, and Cybernetics,* Banff, Canada.
A21	Malinova, M., & Mendling, J. (2018). Identifying Do's and Don'ts Using the Integrated Business Process Management Framework. *Business Process Management Journal, 24*(4), 882–899.
A22	Mishra, A., Das, S. R., & Murray, J. J. (2015). Risk, Process Maturity, and Project Performance: An Empirical Analysis of US Federal Government Technology Projects. *Production and Operations Management, 25*(2), 210–232.
A23	Nadarajah, D., & Syed A. Kadir, S. L. (2016). Measuring Business Process Management Using Business Process Orientation and Process Improvement Initiatives. *Business Process Management Journal, 22*(6), 1069–1078.
A24	Novak, R., & Janeš, A. (2019). Business Process Orientation in the Slovenian Power Supply. *Business Process Management Journal, 25*(4), 780–798.
A25	Okręglicka, M., Mynarzová, M., & Kaňa, R. (2015). Business Process Maturity in Small and Medium-sized Enterprises. *Polish Journal of Management Studies, 12*(1), 121–131.
A26	Ongena, G., & Ravesteijn, P. (2019). Business Process Management Maturity and Performance: A Multi Group Analysis of Sectors and Organization Sizes. *Business Process Management Journal, 26*(1), 132–149.
A27	Proença, D., & Borbinha, J. (2018). Maturity Model Architect: A Tool for Maturity Assessment Support. In *Proceedings of the 20th Conference on Business Informatics,* Vienna, Austria.
A28	Pypłacz, P. (2018). Management and Process Maturity in Polish Small Enterprises. In *Proceedings of the 31st International Business Information Management Association Conference,* Milan, Italy.
A29	Ravesteijn, P., Smit, J., & McGuinness, B. (2016). A Study on the Relation between Business Process Management Maturity and Innovation. In *Proceedings of the 22nd Americas Conference on Information Systems,* San Diego, United States of America.

No	Reference of articles (2015–2019)
A30	Roeser, T., & Kern, E.-M. (2015). Surveys in Business Process Management – A Literature Review. *Business Process Management Journal, 21*(3), 692–718.
A31	Romero, H. L., Dijkman, R. M., Grefen, P. W. P. J., & van Weele, A. J. (2015). Factors that Determine the Extent of Business Process Standardization and the Subsequent Effect on Business Performance. *Business & Information Systems Engineering, 57*(4), 261–270.
A32	Sincorá, L. A., de Oliveira, M. P. V., Zanquetto-Filho, H., & Ladeira, M. B. (2018). Business Analytics Leveraging Resilience in Organizational Processes. *RAUSP Management Journal, 53*(3), 385–403.
A33	Singer, R. (2015). Business Process Management in Small- and Medium-sized Enterprises: An Empirical Study. In *Proceedings of the 7th International Conference on Subject-Oriented Business Process Management,* Kiel, Germany.
A34	Sliż, P. (2018). Concept of the Organization Process Maturity Assessment. *Journal of Economics and Management, 33*(3), 80–95.
A35	Indihar-Štemberger, M., Buh, B., Milanović Glavan, L., & Mendling, J. (2018). Propositions on the Interaction of Organizational Culture with Other Factors in the Context of BPM Adoption. *Business Process Management Journal, 24*(2), 425–445.
A36	Sujová, A., & Remeň, O. (2018). Management of Changes in Business Processes: An Empirical Study in Slovak Enterprises. *Engineering Management in Production and Services, 10*(3), 37–50.
A37	Tarhan, A., Turetken, O., & Ilisulu, F. (2015). Business Process Maturity Assessment: State of the Art and Key Characteristics. In *Proceedings of the 41st Euromicro Conference on Software Engineering and Advanced Applications,* Madeira, Portugal.
A38	Tarhan, A., Turetken, O., & Reijers, H. A. (2016). Business Process Maturity Models: A Systematic Literature Review. *Information and Software Technology, 75,* 122–134.
A39	Tarhan, A., Turetken, O., & Reijers, H. A. (2015). Do Mature Business Processes Lead to Improved Performance? – A Review of Literature for Empirical Evidence. In *Proceedings of the 23rd European Conference on Information Systems,* Münster, Germany.

No	Reference of articles (2015–2019)
A40	Tarhan, A., Turetken, O., & van den Biggelaar, F. J. H. M. (2015). Assessing Healthcare Process Maturity: Challenges of Using a Business Process Maturity Model. In *Proceedings of the 9th International Conference on Pervasive Computing Technologies for Healthcare,* Istanbul, Turkey.
A41	Tătaru, I. M., & Fleacă, E. (2019). Technologies for Modeling Business Processes. *FAIMA Business & Management Journal, 7*(2), 31–41.
A42	van de Kamp, H. G., Smit, J., & Ravesteijn, P. (2017). Relation between Business Process Management Maturity and Innovation. In *Proceedings of the 10th IADIS International Conference Information Systems,* Budapest, Hungary.
A43	van Looy, A. (2015). An Experiment for Measuring Business Process Maturity with Different Maturity Models. In *Proceedings of the 23rd European Conference on Information Systems,* Münster, Germany.
A44	van Looy, A. (2017). A Quantitative Study of the Link Between Business Process Management and Digital Innovation. In J. Carmona, G. Engels, & A. Kumar (Eds.), *Lecture Notes in Business Information Processing, Business Process Management Forum* (pp. 177–192). Springer.
A45	van Looy, A., Poels, G., & Snoeck, M. (2017). Evaluating Business Process Maturity Models. *Journal of the Association for Information Systems, 18*(6), 461–486.
A46	van Looy, A., & Shafagatova, A. (2016). Business Process Performance Measurement: A Structured Literature Review of Indicators, Measures and Metrics. *SpringerPlus, 5*(1), 1–24.
A47	van Looy, A., & van den Bergh, J. (2018). The Effect of Organization Size and Sector on Adopting Business Process Management. *Business & Information Systems Engineering, 60*(6), 479–491.
A48	Vukšić, V. B., Stemberger, M. I., & Vugec, D. S. (2017). Insights into BPM Maturity in Croatian and Slovenian Companies. In *Proceedings of the 40th International Convention on Information and Communication Technology, Electronics and Microelectronics,* Opatija, Croatia.
A49	Widmann, V., de Waal, B. M. E., & Ravesteijn, P. (2018). How Do BPM Maturity and Innovation Relate in Large Companies? In Á. Rocha, H. Adeli, L. P. Reis, & S. Costanzo (Eds.), *Advances in Intelligent Systems and Computing: Vol. 747, Trends and Advances in Information Systems and Technologies* (pp. 87–96). Springer.

No	Reference of articles (2015–2019)
A50	Berger, R., Wellbrock, W., Aksoy, O., & Mulzer, D. (2018). Process Orientation: An Approach to Optimize Cross-company Supply Chains - Insights from a Descriptive Study. In *Proceedings of the 30th Annual NOFOMA Conference,* Kolding, Denmark.
A51	Braunnagel, D., Falk, T., Wehner, B., & Leist, S. (2016). BPM Adoption in Small and Medium-sized Companies in Bavaria. In *Proceedings of the 24th European Conference on Information Systems,* Istanbul, Turkey.
A52	de Waal, B. M. E., Maris, A., & Ravesteijn, P. (2017). BPM Maturity and Performance: The Influence of Knowledge on BPM. *Communications of the IIMA, 15*(2), 1–15.
A53	Milanović Glavan, L., & Bosilj-Vukšić, V. (2017). Examining the Impact of Business Process Orientation on Organizational Performance: The Case of Croatia. *Croatian Operational Research Review, 8*(1), 137–165.
A54	Janeš, A., & Novak, R. (2017). Process Maturity Orientation Measurement. In *Proceedings of the Management International Conference,* Monastier di Treviso, Italy.
A55	Kalinowski, T. B. (2018). Relation Between Business Process Maturity and Performance – Systematic Literature Review. In *Proceedings of the 8th International Conference on Management: Leadership, Innovativeness and Entrepreneurship in a Sustainable Economy,* Czestochowa, Poland.
A56	Kalinowski, T. B. (2018). Business Process Maturity Models Research – A Systematic Literature Review. In *Proceedings of the 33rd International Scientific Conference on Economic and Social Development,* Warsaw, Poland.
A57	Keller, A., & Moormann, J. (2017). The Challenge to Determine a Company's Process Maturity: A Case Study from the Financial Services Industry. *European Journal of Management Issues, 25*(2), 86–91.
A58	Lasrado, L. A., Vatrapu, R., & Mukkamala, R. R. (2017). Whose Maturity Is It Anyway? The Influence of Different Quantitative Methods On The Design and Assessment of Maturity Models. In *Proceedings of the 25th European Conference on Information Systems,* Guimarães, Portugal.
A59	Maris, A., Exalto-Sijbrands, M., & Ravesteijn, P. (2016). Improving Internal Collaboration a Business Process Management Maturity Approach. In *Proceedings of the 13th International Conference on Enterprise Systems, Accounting and Logistics,* Athens, Greece.

No	Reference of articles (2015–2019)
A60	Miri-Lavassani, K., & Movahedi, B. (2018). Achieving Higher Supply Chain Performance via Business Process Orientation. *Business Process Management Journal, 24*(3), 671–694.
A61	Pejić Bach, M., Bosilj-Vukšić, V., Suša Vugec, D., & Stjepić, A.-M. (2019). BPM and BI in SMEs: The Role of BPM/BI Alignment in Organizational Performance. *International Journal of Engineering Business Management, 11,* 1-16.
A62	Roslyakova, L., & Ravesteijn, P. (2017). Relation between Business Process Management Maturity and Innovation. In *Proceedings of the 13th European Conference on Management, Leadership and Governance,* London, United Kingdom.
A63	Sawicki, P., & Jaworek, P. (2017). Business Process Maturity of the Transport-forwarding-logistics Sector in Poland. *Research in Logistics and Production, 7*(4), 337–350.
A64	Aberle, D., & Henkel, J. (2017). The Development of a Questionnaire to Measure Business Process Maturity. *European Journal of Management Issues, 25*(3-4), 125–134.
A65	Szelagowski, M., & Berniak-Woźny, J. (2020). The Adaptation of Business Process Management Maturity Models to the Context of the Knowledge Economy. *Business Process Management Journal, 26*(1), 212–238.
A66	Buh, B., Kovačič, A., & Indihar-Štemberger, M. (2015). Critical Success Factors for Different Stages of Business Process Management Adoption – A Case Study. *Economic Research, 28*(1), 243–258.
A67	Cats, T., & Ravesteijn, P. (2017). The Relation Between Process Management and Innovation – A comparison of the IT and Manufacturing Industries. In *Proceedings of the 30th Bled eConference: Digital Transformation - From Connecting Things to Transforming our Lives,* Bled, Slovenia.
A68	Kahrovic, E., & Krstic, B. (2015). The Effects of Business Process Management on the Improvement of Firm Performances. *Industrija, 43*(4), 67–87.
A69	Mijoska, M., & Levkov, N. (2015). Business Process Orientation Construct Analysis in Companies in the Republic of Macedonia. In *Proceedings of the 38th International Convention on Information and Communication Technology, Electronics and Microelectronics,* Opatija, Croatia.

Digital Appendix B. Categorization of the Studies

	Research content							Research focus			
No.	R	D	C/M	ES Dev	ES App	ES Val	TA	Dev	App	Val	MA
A1		x			x				x		
A2	x	x			x			x			
A3		x			x				x		
A4	x	x			x				x		
A5							x				x
A6						x				x	
A7						x				x	
A8		x			x				x		
A9						x				x	
A10						x				x	
A11	x	x						x			
A12							x				x
A13				x							x
A14					x				x		
A15						x				x	
A16						x				x	
A17							x				x
A18						x				x	
A19			x								x
A20		x					x				x
A21							x				x
A22		x				x				x	
A23							x				x

No.	Research content: R	D	C/M	ES Dev	ES App	ES Val	TA	Research focus: Dev	App	Val	MA
A24		x			x				x		
A25		x			x				x		
A26		x				x				x	
A27							x				x
A28		x			x				x		
A29		x				x				x	
A30							x				x
A31							x				x
A32						x				x	
A33		x			x	x				x	
A34	x							x			
A35							x				x
A36					x				x		
A37		x					x				x
A38							x				x
A39						x					x
A40		x			x				x		
A41			x								x
A42						x				x	
A43		x			x				x		
A44					x				x		
A45							x				x
A46							x				x
A47		x			x				x		
A48		x			x				x		

No.	Research content							Research focus			
	R	D	C/M	ES Dev	ES App	ES Val	TA	Dev	App	Val	MA
A49					x				x		
A50	x				x				x		
A51					x				x		
A52						x				x	
A53		x				x				x	
A54					x				x		
A55							x				x
A56							x				x
A57					x		x		x		
A58							x				x
A59					x				x		
A60						x				x	
A61						x				x	
A62						x				x	
A63					x				x		
A64			x				x				x
A65							x				x
A66						x				x	
A67						x				x	
A68						x				x	
A69					x		x		x		

	BPMM													
No.	**BPM-CF**	**BPMM-FIS**	**BPMM-HR**	**BPMM-OMG**	**BPO-MF**	**BPO-MM**	**PEMM**	**PMMA**	**vPMM**	**CMMI**	**PPI**	**BPM-MC**	**Other**	**No explicit ref**
A1														x
A2				x										
A3										x				
A4	x									x				
A5														x
A6													x	
A7													x	
A8													x	
A9				x										
A10													x	
A11														x
A12														x
A13														x
A14														x
A15	x									x				
A16						x								
A17														x
A18														x
A19														x
A20	x			x		x	x							
A21														
A22										x				
A22										x				

	BPMM													
No.	**BPM-CF**	**BPMM-FIS**	**BPMM-HR**	**BPMM-OMG**	**BPO-MF**	**BPO-MM**	**PEMM**	**PMMA**	**vPMM**	**CMMI**	**PPI**	**BPM-MC**	**Other**	**No explicit ref**
A23														x
A24						x								
A25				x										
A26													x	
A27														x
A28										x				
A29													x	
A30														x
A31														x
A32				x										
A33							x							
A34														x
A35						x								
A36										x				
A37	x	x	x	x	x	x	x	x	x					
A38	x	x	x	x	x	x	x	x	x					
A39														
A40				x										
A41										x				
A42													x	
A43							x				x	x		
A44														x
A45														x

BPMM

No.	BPM-CF	BPMM-FIS	BPMM-HR	BPMM-OMG	BPO-MF	BPO-MM	PEMM	PMMA	vPMM	CMMI	PPI	BPM-MC	Other	No explicit ref
A46														x
A47													x	
A48											x			
A49													x	
A50														x
A51													x	
A52													x	
A53						x								
A54												x		
A55														x
A56														x
A57				x										
A58														x
A59													x	
A60						x								
A61											x			
A62													x	
A63										x				
A64	x													
A65				x										
A66						x					x			
A67													x	
A68														x

BPMM

No.	BPM-CF	BPMM-FIS	BPMM-HR	BPMM-OMG	BPO-MF	BPO-MM	PEMM	PMMA	vPMM	CMMI	PPI	BPM-MC	Other	No explicit ref
A69						x								

III.6 Appendix B. Overview of the Five Analyzed BPMMs

Criteria for transparency	MM-AND	MM-BER	MM-CHA	MM-FRO	MM-SLI
Literature review	x	x		x	x
Case study					
Delphi study					
Focus group					
Procedure model		x			x
Demonstration with prototype					
Experiment with prototype or system					
Benchmarking					
Survey					
Expert interview	x				
Focus group					
Others	x				
Case study			x	x	
Field experiment					
Survey		x			
Expert interview					
Focus group					
Descriptive	x	x	x	x	x
Prescriptive	x				x
Comparative					x
Number of levels	x	x	x		x
Descriptor for each level	x	x	x		x
Generic description of each level	x	x	x		x

Criteria for transparency	MM-AND	MM-BER	MM-CHA	MM-FRO	MM-SLI
Number of dimensions	x	x	x	x	x
Number of elements for each process area	x	x	x	x	x
Description of each activity					
Intersubjectively verifiable criteria	x	x			x
Assessment methodology			x		x
Improvement measures					
Decision calculus to select measures					
Decision methodology					
Organizational structure		x		x	x
Strategic alignment	x	x	x	x	x
Culture		x	x		
Supplier orientation		x	x		
Customer orientation	x	x	x		
Process focus			x		
Process owner		x	x		
Definition and documentation	x	x	x	x	x
Design of processes	x	x	x	x	
Measurement of processes	x	x	x	x	
Improvement of processes		x	x		x
Support by IT-tools	x	x	x	x	
Design of jobs and workplace				x	
Employee development		x	x	x	x
Employee involvement and motivation		x			x
Employee information exchange		x	x		

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Article IV. How to Make Business Process Maturity Models Better – Drawing on Design Science Research

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Abstract. Business process maturity models are considered a suitable tool for initiating and guiding organizational transformation. However, there are recent indications that the models that are developed in academia are only rarely used in business practice. In the context of this article, we suspect that this is due to a lack of the models' reproducibility and replicability, which is also reflected in the quality of the models' publication outlets. To address this problem, we draw on the foundations of design science research (DSR). Methodically, we conduct a literature review to identify a set of criteria that increases transparency as the fundamental prerequisite of reproducibility and replicability. These criteria can be valuable for (1) supporting researchers in ensuring transparency during maturity model development to maintain high methodological standards, (2) guiding peer reviewers in the evaluation of papers eligible for publication, and (3) comparing existing maturity models and identifying their shortcomings.

Keywords. Design Science · Design Science Research · Maturity Model · Business Process Management · Business Process Maturity Model · Transparency

IV.1 Introduction

To succeed in an environment with increasing market dynamics and high levels of competitive pressure, it is crucial for organizations to constantly adapt their business processes. In such an attempt, business process maturity models (BPMMs) are seen as an important tool for organizational transformation (Kalinowski, 2018) when (1) determining the company's status quo, (2) mapping its development path to excellence, and (3) comparing capabilities within and between companies (Felch et al., 2018). As a response to practical interest, academia has developed and published many new maturity models over the last decades (de Bruin et al., 2005; Wendler, 2012). However, recent studies have shown that despite the great supply of such models, the degree of application in practice is in fact unexpectedly low (Felch et al., 2019; Jamaluddin et al., 2010). This observation leads to the question of why this is the case.

One possible reason could be reproducibility and replicability issues with the published models. In past years, discussions about reproducibility and replicability have repeatedly taken place in various research domains (Aguinis et al., 2017; Aguinis et al., 2018; Bergh et al., 2017; Campbell et al., 2014). In that regard, Campbell et al. (2014) and, in particular, Aguinis et al. (2018) criticize the lack of methodological transparency, which they define "[...] as the degree of detail and disclosure about the specific steps, decisions, and judgment calls made during a scientific study" (Aguinis et al., 2018, p. 84). Enhancing methodological transparency is not only a prerequisite for applying research in practice but also crucial for credibility as well as trustworthiness, which are both typical criteria for academic research in general (Aguinis et al., 2018; O'Kane et al., 2021). Therefore, if the assumption of a lack of reproducibility and replicability is justified, this should be reflected in the publication outlets. High-ranked journals are known to place particular emphasis on methodological standards, so maturity models that are difficult to apply should be difficult to publish in those outlets. Against this background, the first leading research question, which motivates the remainder of this paper, is as follows:

(1) How well recognized are the publication outlets of released BPMMs?

The findings of the analysis indicated that the assumption of a lack of reproducibility and replicability in many cases may not be entirely unfounded. For this reason, this paper pursues the goal of developing guidelines that can be used by researchers to ensure a high degree of methodological transparency as a prerequisite for better reproducibility and replicability and thus improve the applicability of their BPMM. In that attempt, we draw on design science research (DSR). Because the intention of DSR is to enhance problem-solving capabilities, various authors consider the application of DSR as a methodological base for the development of maturity models to be appropriate (Becker et al., 2009; Mettler & Rohner, 2009; Wendler, 2012). Becker et al. (2009) transfer the process model by Hevner et al. (2004) to the process of creating maturity models and suggest a procedural model. Consequently, basic guidance for the model design exists in the literature; however, criteria for researchers to prove the methodological transparency of BPMMs do not yet exist. This lack leads to the two following further research questions:

(2) Which criteria regarding DSR can BPMMs meet to enhance their methodological transparency and thus their reproducibility?

(3) To what extent do current BPMMs meet these criteria?

Thus, the paper contributes to existing knowledge (1) by focusing the developers' effort on key criteria that will guide them to present their BPMMs in a more transparent and replicable way and (2) by providing reviewers with a profound checklist that they can rely on for evaluation of future submitted models.

The remainder of this paper is structured as follows: The next section analyzes the publication outlets of BPMMs. Subsequently, the theoretical background focusing on maturity models in the context of DSR is provided, and criteria based on DSR for higher methodological transparency are suggested. Thereafter, five BPMMs are analyzed based on the proposed criteria. The paper closes with a summary of the key findings, theoretical and managerial implications, and an outline for future research opportunities.

IV.2 Publication Outlets of Business Process Maturity Models

In the course of an academic career, the decision about an article's publication outlet is often made. For years, there has been significant interest in creating systematic and objective evaluation methods to determine the quality of a journal and thus articles. Various authors, including Garfield (1999) and Hirsch (2005), have derived so-called impact factors. Researchers aim to publish in journals with the highest possible impact factor and a broad scope. Accordingly, the journal's recognition is a decisive factor for a BPMM achieving the highest possible application and dissemination rate. For the purpose of this paper, we draw on the literature review by Tarhan et al. (2016) and consider the articles identified by them that have released a maturity model in an academic journal (1990–2014). This criterion accounts for six out of all 61 publications identified by Tarhan et al.: (1) Hammer (2007), (2) Rohloff (2010), (3) Moradi-Moghadam et al. (2013), (4) Saco (2008), (5) Cronemyr and Danielsson (2013), and (6) Jochem et al. (2011).

To determine the value of these six publications, we rely on three impact factors: (1) the index by Thomson Reuters (Reuters Index) (Web of Science Group), (2) the index by Hirsch (H-index) (Hirsch, 2005), and (3) the SCImago Journal Rank (SJR) indicator (SCImago, 2019). In general, the higher the impact factor, the higher the ranking of the journal and thus the higher the reputation of the published paper. The impact factors are based on data from the website SJR – SCImago Journal & Country Rank (www.scimagojr.com, as of January 2020). The International Journal of Business Process Integration and Management reveals by far the lowest impact factors (Reuters Index: 0.5, H-index: 17, SJR: 0.1). On the other hand, this is contrasted by the result of the Harvard Business Review, which reaches the highest values for the Reuters Index (13.2) and the H-index (161). Surprisingly, it performs poorly within the SJR index (0.2). Beyond that, the mean value of each impact factor (Ø publication outlets) is calculated (see Table IV.1). Compared to the mean value of all journal publications identified by Tarhan et al. (2016), only minor differences regarding the impact factors can be indicated.

To make valid statements about the journals' influence and relevance, these means are compared with the average impact factor of the main overarching subject categories of the six journals. Therefore, the top 50 journals were filtered using the SJR website, and average impact factors were calculated (see Table IV.1). In the case of the H-index and SJR, the lowest mean value of each subject category reaches a value that is far higher than the mean values of the six journals (Ø publication outlets).

Publication outlet of the article	**Reuters Index**	**H-index**	**SJR**
Ø Publication outlets (six released BPMMs)	3.9	59.8	0.4
Ø Publication outlets (25 journal articles as identified by Tarhan et al. (2016))	3.4	61.8	0.7
Ø Business and International Management	5.3	103.1	3.1
Ø Business, Management and Accounting (misc.)	3.7	84.5	1.9
Ø Economics and Econometrics	5.6	137.2	7.4
Ø Industrial and Manufacturing Engineering	5.2	101.8	1.8
Ø Information Systems	6.0	93.3	1.8
Ø Management of Technology and Innovation	4.7	98.4	2.5
Ø Management Science and Operations Research	3.7	85.2	1.8
Ø Strategy and Management	5.6	123.7	3.5

Table IV.1. Impact factors of the released models (1990–2014) and comparison with status quo

The Reuters Index reaches the lowest threshold. The comparison indicates that the BPMMs are published in low-threshold journals, which have little relevance and influence on the scientific community as well as on future research. Reasons for publication in less-relevant journals might be an insufficient theoretical foundation, limited model validation and unsatisfactory model documentation and thus non-reproducibility or non-replicability, which seems to be a general problem with maturity models (Albliwi et al., 2014; Mettler et al., 2010). Therefore, it is hardly surprising that maturity models are not published in higher-quality journals, as the replicability of the design/concept and method are key criteria that are normally used in peer review processes and by editors (Bornmann et al., 2008). Thus, methodological transparency is not only a prerequisite for the replicability, credibility, and trustworthiness of the results but can also simultaneously increase the chance of acceptance in higher-value journals. This in turn can have a positive influence on model dissemination and application in practice. Consequently, it seems necessary to provide authors with criteria that guide them in demonstrating methodological transparency of BPMMs. This paper is intended to contribute to this research gap by borrowing from DSR as an appropriate methodological foundation for model design.

IV.3 Maturity Models in the Context of DSR

Whereas natural-behavioral science seeks to identify empirical laws, DSR is concerned with solving real-world problems or necessities (Hevner et al., 2004; March & Smith, 1995). Hevner and Chatterjee (2010) describe DSR as a "[...] research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artifacts, thereby contributing new knowledge to the body of scientific evidence" (Hevner & Chatterjee, 2010, p. 5). In addition, DSR can also improve the state of the art by more effective and efficient solutions (Kuechler & Vaishnavi, 2008; March & Smith, 1995). In general, DSR involves two primary and closely related activities: (1) building, and (2) evaluating whether the previously defined requirements are met and how well the artefact performs (Hevner et al., 2004; March & Smith, 1995; Vaishnavi et al., 2004). This prevailing loop was adopted by Hevner et al. (2004) and extended to his commonly accepted process model for the execution and documentation of DSR. The model distinguishes three essential DSR segments: (1) environment, (2) information systems (IS) research, and (3) knowledge base (see Figure IV.1, adapted from Hevner et al. (2004)). In addition, other models exist, for example, those by March and Smith (1995) or Peffers et al. (2007). As these models show only minor differences and contain the three main DSR elements, such as problem definition, development, and evaluation (Dresch et al., 2015), we draw on the most cited work by Hevner et al. (2004).

In the context of DSR, maturity models themselves can be interpreted as an artefact; therefore, the application of the design science paradigm is meaningful (Becker et al., 2009; Pöppelbuß & Röglinger, 2011; Wendler, 2012). Considering the existing literature, Mettler and Rohner (2009) describe their artefact type as a "somehow in-between" (Mettler & Rohner, 2009, p. 2) model and method, since it can both identify the current status and derive a goal-driven development path to improve the situation. Reviewing the prevailing literature, few researchers present frameworks that serve as a guide for conducting DSR when developing maturity models. Becker et al. (2009) criticize insufficient documentation of the development processes and thus initially formulate process requirements.

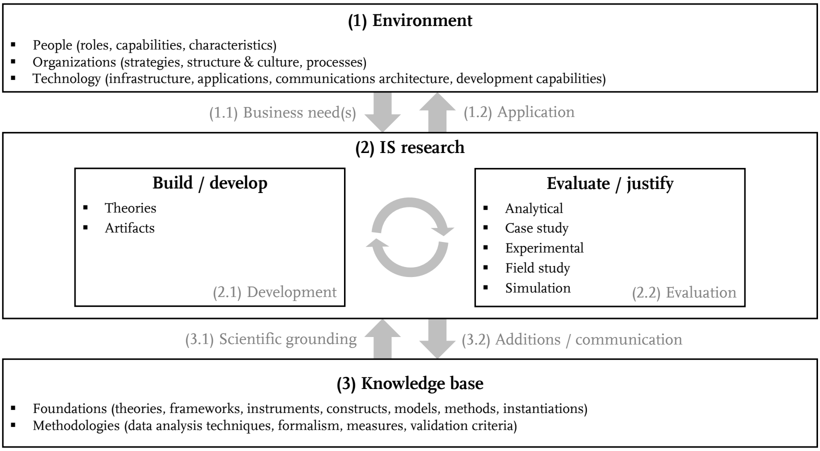

Figure IV.1. DSR process model

This results in a five-step procedure model that is derived from the process model by Hevner et al. (2004) and guides the model creation and its application. In addition, further procedure models exist that suggest similar steps, such as those of de Bruin et al. (2005) or Maier et al. (2009). Motivated by the question of "[...] whether high quantity goes along with high quality" (Pöppelbuß & Röglinger, 2011, p. 1), Pöppelbuß and Röglinger (2011) derive general design principles based on current literature. Three interdependent principles can be differentiated: (1) basic principles, (2) principles for descriptive purpose, and (3) principles for prescriptive purpose. In addition, Gregor and Hevner (2013) present a well-founded publication scheme for DSR issues, which specifies individual steps to communicate the main contributions to the knowledge base. Despite detailed instructions, the authors point out that the artefact description section is dependent on artefact type, research focus and outlet and therefore adjustments for maturity models are necessary. In fact, procedure models, design principles and publication schemes are meaningful and beneficial. However, these studies mainly focus on structural components helping to develop and communicate maturity models in general. Therefore, essential components of DSR, such as development and evaluation criteria and recourse to the knowledge base, are omitted. Furthermore, none of the articles specifically addresses how researchers can present their BPMMs in a transparent and replicable manner according to DSR and which criteria are essential for the limited space in journal or conference articles.

IV.4 Criteria for Methodological Transparency of Business Process Maturity Models

This section outlines criteria for researchers to accomplish a high degree of methodological transparency. These criteria represent a first step towards solving the described issue. A literature search was performed in common digital databases (Ebsco, Google Scholar, ScienceDirect, Web of Science). The search terms included 'maturity model', 'capability model', 'design science', 'transparency' 'business process management', 'business process', 'design', 'evaluation', and 'application'. It should be noted that our search was conducted only over academic literature and excluded publications such as white papers, expressions of opinions, student papers, PowerPoint presentations, and papers published in non-academic journals and magazines. After eliminating duplicates and reviewing the content of the originally selected articles, a total of 16 relevant studies were identified (Becker et al., 2009; de Bruin et al., 2005; Fraser et al., 2002; García-Mireles et al., 2012; Helgesson et al., 2012; Lahrmann et al., 2010; Lasrado et al., 2015; Maier et al., 2009; March & Smith, 1995; Mettler, 2009, 2010; Mettler et al., 2010; Pöppelbuß & Röglinger, 2011; Sonnenberg & vom Brocke, 2012; van Steenbergen et al., 2010; Wendler, 2012). The respective criteria were synthesized from the articles and grouped according to the three main DSR segments by Hevner et al. (2004) (see Table IV.2). It is not required to meet all the criteria; rather, authors should select those that are suitable for their BPMM design process.

Business need(s) (1.1). First, the environment initiates DSR by determining the problem space of the real world. People recognize business needs based on their roles, abilities and characteristics, which are then assessed in terms of organizational and technical systems. Thus, the problem and its solution requirements can be perceived by the researcher. Thus, to justify the creation of a new maturity model, the current need must be clearly stated (Becker et al., 2009; de Bruin et al., 2005). The relevance and usefulness of new maturity models can be substantiated by a comprehensive literature overview of existing models (Becker et al., 2009; Sonnenberg & vom Brocke, 2012). Therefore, the aim is to identify essential studies of the same or similar application domains, compare them and highlight research gaps or shortcomings. In addition, evidence of a real-world problem can be obtained through surveys, interviews with experts or focus groups and through the appraisal of practical initiatives (Becker et al., 2009; Sonnenberg & vom Brocke, 2012). The weakest evidence of the commitment of model design is an assertion provided by the researcher (Sonnenberg & vom Brocke, 2012).

Application of the artefact (1.2). Once the artefact has been created, it needs to be validated in a field test against its preassigned requirements (Helgesson et al., 2012; Maier et al., 2009; Wendler, 2012). It is necessary that the researcher examines to what extent the model is consistent with reality and which implications the model application has on the environment and users (Sonnenberg & vom Brocke, 2012). Moreover, the developed model has to be consistent itself and to already existing knowledge (Sonnenberg & vom Brocke, 2012). Drawing on DSR, it is crucial that the model solves an existing problem or at least improves the current solution. Consequently, the models' effectiveness and efficiency are to be measured (Becker et al., 2009; Sonnenberg & vom Brocke, 2012). Moreover, to make valid statements about the models' acceptance and dissemination potential, general validity has to be documented. Methodologically, field experiments, surveys, expert interviews and focus groups are suitable for model application (Mettler, 2010; Sonnenberg & vom Brocke, 2012; Wendler, 2012). Beyond that, the application criteria can be examined through a case study (Sonnenberg & vom Brocke, 2012), which, according to Wendler (2012)'s analysis, experiences the most frequent use.

DSR seg.	Dimension	Element	Criteria for methodological transparency
(1) Environment	(1.1) Business need(s)	Real-world problem*	Assertion, literature review, review practitioner initiatives, expert interview, focus group, surveys
	(1.2) Application of the artefact	Application method*	Case study, field experiment, survey, expert interview, focus group
		Application criteria*	Applicability, effectiveness, efficiency, fidelity with the real-world phenomenon, generality, impact on artefact environment and user, internal or external consistency
(2) IS research	(2.1) Development of the artefact	Development method*	Literature review, case study, Delphi study, focus group
		Procedure model	E.g., Becker et al. (2009), de Bruin et al. (2005), Mettler (2009), Maier et al. (2009)
	(2.2) Evaluation of the artefact	Evaluation method*	Demonstration with prototype, experiment with prototype or system, benchmarking, survey, expert interview, focus group
		Evaluation criteria	Method: ease of use, efficiency, generality, operationality Model: completeness, fidelity with real-world phenomena, internal consistency, level of detail, robustness
(3) Knowledge base	(3.1) Scientific grounding	Basic maturity models	Leading BPMMs, e.g., BPM capability framework by Rosemann and de Bruin (2005), BPMM by Object Management Group (2008)

DSR seg.	Dimension	Element	Criteria for methodological transparency
		Appropriate literature	Most popular BPMM literature, e.g., Lockamy and McCormack (2004), Rosemann and de Bruin (2005), Röglinger et al. (2012)
	(3.2) Additions/ Artefact	Purpose of use	Descriptive, prescriptive, comparative
		Basic components	Number of levels, descriptor for each level, generic description of the characteristics of each level, number of dimensions, number of elements for each process area, description of each activity as it might be performed at each maturity level
		Components of descriptive maturity models	Intersubjectively verifiable criteria for each maturity level and level of granularity, target group-oriented assessment methodology
		Components of prescriptive maturity models	Improvement measures for each maturity level and level of granularity, decision calculus for selecting improvement measures, target group-oriented decision methodology

Table IV.2. Criteria for methodological transparency of BPMMs[18]

Development (2.1). The definition of the requirements is followed by the construction of the artefact, whereby the existing knowledge base is incorporated at this point (Hevner et al., 2004). To prevent arbitrariness in the design process and provide theoretical sound models, various procedure

[18] The elements marked with an asterisk (*) can be used independently of the artefact type in the area of DSR.

models have been created specifying standardized and methodological steps (García-Mireles et al., 2012; Lahrmann et al., 2010; Lasrado et al., 2015). Leading procedure models are the model by de Bruin et al. (2005) and that by Becker et al. (2009). Further models with similar process steps exist, such as those by Mettler (2009) or Maier et al. (2009). To define the model content, mainly explorative research methods, including case studies, Delphi studies, and focus groups, will be applied (Becker et al., 2009; de Bruin et al., 2005; Lahrmann et al., 2010; van Steenbergen et al., 2010). In addition, the recourse to the literature reviews or prevailing literature, in general, constitutes another possible approach (Becker et al., 2009; de Bruin et al., 2005; Lahrmann et al., 2010; Maier et al., 2009).

Evaluation (2.2). The development is complemented by the model evaluation, which is repeated until an innovative and useful artefact is generated and the requirements are fulfilled. Various elements can be identified that need to be revised for model adaptation in practice. In this phase, either simulations or experiments can be conducted methodologically (Helgesson et al., 2012; Sonnenberg & vom Brocke, 2012). Alternatively, interviews with experts or people independent of the development process as well as moderated group discussions are suitable (Becker et al., 2009; Helgesson et al., 2012; Sonnenberg & vom Brocke, 2012). Since different artefact types do not reveal similar characteristics, the use of artefact-dependent evaluation criteria is necessary.

Maturity models are classified as “somehow in-between” (Mettler & Rohner, 2009, p. 2) models and methods; consequently, the criteria of both artefact types might be checked during the model evaluation. Drawing from DSR, the evaluation aims at the quality of use when interacting with the model, as well as the usability (March & Smith, 1995; Sonnenberg & vom Brocke, 2012). In addition, it should be verified whether the model is complete and consistent in itself (Becker et al., 2009; March & Smith, 1995; Sonnenberg & vom Brocke, 2012). Furthermore, the extent to which the model represents reality and whether the level of detail described corresponds to the users’ expectations should be examined (Maier et al., 2009; March & Smith, 1995; Sonnenberg & vom Brocke, 2012). The criteria of generality, robustness and efficiency should also be addressed to provide broader feedback (March & Smith, 1995; Mettler et al., 2010; Sonnenberg & vom Brocke, 2012).

Scientific grounding (3.1). The knowledge base contributes to the scientific grounding of artefacts through existing theoretical know-how, which increases the innovative power of the novel BPMM and ensures scientific rigor (Hevner, 2007). Therefore, it is suitable to seize on theories, instruments or established BPMMs that have solved the same or similar research problems for one's own work. In the context of BPMMs, the following most popular literature can be recommended: Lockamy and McCormack (2004), Rosemann and de Bruin (2005), and Röglinger et al. (2012). As an example of established BPMMs, we refer to Tarhan et al. (2016). These authors were able to identify nine models that are increasingly relied upon in the area of BPM, for example, the BPM capability framework by Rosemann and de Bruin (2005), the business process orientation maturity framework by Willaert et al. (2007) or the BPMM by the Object Management Group (OMG, 2008). Such leading models can likewise be identified for other domains and adapted to current needs.

Additions/Communication (3.2). In addition, the knowledge base can be further enriched by incorporating new theories and methods developed during the DSR process. By creating a new BPMM, a significant contribution to the existing knowledge base and practice can be achieved. To ensure this achievement, the communication of essential model elements in an appropriate manner is necessary (Becker et al., 2009; de Bruin et al., 2005; Pöppelbuß & Röglinger, 2011). Therefore, it is crucial to indicate the models' purpose: descriptive, prescriptive or comparative (Pöppelbuß & Röglinger, 2011; van Looy, 2014). In addition, core components need to be documented, in particular, the title and description for each maturity level, the number of dimensions and elements, and a description for each activity (Fraser et al., 2002; Maier et al., 2009; Pöppelbuß & Röglinger, 2011). Depending on the model purpose, further model parts are to be published to achieve high replicability. Therefore, assessment criteria and methodology for descriptive maturity models are as crucial as improvement measures, decision criteria and methodology for models with prescriptive purpose (Pöppelbuß & Röglinger, 2011).

IV.5 Review of Recently Published Business Process Maturity Models

Using the latest BPMMs, methodological transparency was examined by means of the literature-based criteria. Since Tarhan et al. (2016) review only considers studies up to 2014, a literature search for newly released BPMMs (including the backtracking of footnotes and searching for citations) until 2019 was performed. Based on Tarhan et al. (2016)'s search parameters, similar search terms ((‘process maturity’ OR ‘process management maturity’ OR ‘BPM maturity’ OR ‘process management capability’ OR ‘BPM capability’) OR (‘business’ AND (‘maturity model’ OR ‘capability model’)) OR (‘business maturity’ OR ‘business capability’) OR (business AND (‘process orientation’) AND maturity)) and digital databases (ACM, Ebsco, Emerald, ScienceDirect, Scopus, SpringerLink, Web of Science, Wiley) were used. Initially, 5,221 references were retrieved, with 69 of those considered relevant for further analysis. These were classified in terms of content using the scheme of Tarhan et al. Accordingly, the five models released between 2015–2019 were selected: (1) MM-AND (model by Andriani et al., 2018), (2) MM-BER (model by Berger et al., 2018), (3) MM-CHA (model by Chaghooshi et al., 2016), (4) MM-FRO (model by Froger et al., 2019), and (5) MM-SLI (model by Sliż, 2018). To provide valid statements about the methodological transparency of BPMMs, a structured content analysis was conducted (Krippendorff, 2019). To ensure the consistency of the coding process, a codebook was developed based on the previously derived criteria, which includes their description and application. Each article represents a unit of analysis. First, coder A, who developed the criteria, coded the entire articles based on the codebook. To confirm that the application of the criteria was not limited to one researcher, a second coder (coder B) was also involved. Coder B has been working intensively with maturity models for several years and is thus familiar with this topic. Before coding the five models independently using MAXQDA Plus 2018 Software, coder B received a short introduction to the codebook. The researchers applied the deductive category system consisting of the criteria of the previous section. Criteria that are not included in the codebook but mentioned in the articles were assigned to the category ‘others’ and analyzed separately. This category was used exclusively for the evaluation method of MM-AND, as informal interviews, secondary documents and observation were applied in addition to expert interviews. Upon finishing the coding process, both files were merged, and coded text sections were compared against each other to calculate the level of agreement. An “agreement rate” (representing the number of matching recordings divided by the number of all recordings) of 77.61% was achieved (Neuendorf, 2017, p. 174). This value falls within the range that is considered reliable (Neuendorf, 2002, p. 143). Before data interpretation, all disagreements were discussed until a consensus decision was reached (similar to Mir et al. (2018) and Seuring (2008)). The presentation of the analysis with regard to methodological transparency is based on the three DSR segments: environment, IS research, and knowledge base (see also Table IV.3).

Environment. With the exception of MM-BER, all the authors name reasons for the creation of their models, mainly using literature reviews (MM-AND, MM-CHA, MM-FRO, MM-SLI). First, the authors compare established maturity models, highlight research gaps, shortcomings or model problems and thus justify the design of a new model. In contrast, MM-BER does not provide any motivation. It is also striking that more elaborate methodologies, such as expert interviews or surveys, are not considered to justify the model construction. For model application in practice, Chaghooshi et al. and Froger et al. perform case studies, which Wendler (2012) considers to be the most frequently used methodology. Berger et al. apply a questionnaire for data collection. However, none of them explain their methodology in detail. Although the methodology is discussed, criteria determining a successful application are not outlined. Whether criteria have been applied at all remains open. Furthermore, the articles by Andriani et al. and Sliz do not report on any future research activities focusing on application in practice.

Dim.	Element	Criteria for methodological transparency	MM-AND	MM-BER	MM-CHA	MM-FRO	MM-SLI
Business need(s)	Real-world problem	Assertion	x				x
		Literature review	x		x	x	x
		Review practitioner initiatives					
		Expert interview					
		Focus group					
		Surveys					
Application of the artefact	Application method	Case study			x	x	
		Field experiment					
		Surveys		x			
		Expert interview					
		Focus group					
	Application criteria	Applicability					
		Effectiveness					
		Efficiency					
		Fidelity with the real-world phenomenon					
		Generality					
		Impact on artefact environment & user					
		Internal or external consistency					
Development of the artefact	Development method	Literature review	x	x		x	x
		Case study					
		Delphi study					
		Focus group					
	Procedure model	Procedure model		x			x
Evaluation of the artefact	Evaluation method	Demonstration with prototype					
		Experiment with prototype or system					
		Benchmarking					
		Survey					
		Expert interview	x				
		Focus group					
		Others	x				

Dim.	Element	Criteria for methodological transparency	MM-AND	MM-BER	MM-CHA	MM-FRO	MM-SLI
	Evaluation criteria	Ease of use					
		Efficiency					
		Generality					
		Operationality					
		Completeness					
		Fidelity with real-world phenomena					
		Internal consistency					
		Level of detail					
		Robustness					
Scientific grounding	Basic MM	Basic MM	x		x		
	Appropriate literature	MM-related literature	x	x	x	x	x
Additions/ Artefact communication	Purpose of use	Descriptive	x	x	x	x	x
		Prescriptive	x				x
		Comparative					x
		Number of levels	x	x	x		x
		Descriptor for each level	x	x	x		x
		Generic description of each level	x	x	x		x
		Number of dimensions	x	x	x	x	x
		Number of elements	x	x	x	x	x
		Description of each activity					
	Components of descriptive MMs	Intersubjectively verifiable criteria	x	x			x
		Target group-oriented assessment methodology			x		x
	Components of prescriptive MMs	Improvement measures					
		Decision calculus to select measures					
		Target group-oriented decision methodology					

Table IV.3. Overview of the analysis of the five BPMMs

IS research. Although procedure models for the creation of maturity models have been published for approximately ten years, the application is rather low. Berger et al. and Sliz apply the model by Becker et al. (2009), while Berger et al. additionally rely on the concept by Mettler (2010). The design process and content definition can be supported by different methods. Andriani et al., Berger et al., Froger et al., and Sliz rely exclusively on existing literature. According to Andriani et al., an extensive evaluation at the end of the design phase was performed. Therefore, various methods, including case studies and interviews, were applied as data collection sources. No indications were found that evaluation criteria were used to guide the model improvement. Moreover, the adjustments within the model are not part of the published article. In MM-BER, MM-CHA, MM-FRO, and MM-SLI evaluation steps are not reported. Whether no evaluation took place or whether the evaluation is not communicated in the context of the article remains open.

Knowledge base. All five models are based on existing publications related to maturity models or BPM. The prevailing publications are mainly used to derive model dimensions and elements. MM-AND takes advantage of American Productivity and Quality Center (2018)'s process classification framework for this purpose, and MM-CHA adopts remarks of Rosemann and de Bruin (2005) and Rosemann et al. (2006), whereas MM-SLI relies on a Polish publication. Both MM-BER and MM-FRO refer to van Looy (2014) and van Looy et al. (2017) for different purposes (MM-BER for the model structure, and MM-FRO for the assessment framework). In addition, Andriani et al. choose the BPMM by the Object Management Group (OMG, 2008) as the base for their new model, whereas Chaghooshi et al. use the Capability Maturity Model Integration by the Software Engineering Institute (Software Engineering Institute [SEI]), as well as the BPM capability framework by Rosemann and de Bruin (2005). Within all five models, a scientific grounding of individual model elements can be verified. Each BPMM reveals its intended purpose of use. A descriptive purpose can be determined for all models. Furthermore, MM-AND and MM-SLI aim at a prescriptive purpose, while MM-SLI also claims to serve the comparative purpose. The basic components are listed for almost every maturity model (MM-AND, MM-BER, MM-CHA, MM-SLI) and thus achieve the highest degree of fulfillment.

Aside from the criterion "description of each activity as it might be performed at each maturity level", which is not considered, although it is essential for the model applicability. The documentation of components for descriptive models is provided by four models. MM-AND, MM-BER, and MM-SLI define characteristics that are essential for the fulfillment of the individual maturity levels. The required description of the characteristics is not listed in any of the articles. MM-CHA and MM-SLI present assessment methodologies to determine the actual situation of the company. In all cases, a comprehensive documentation that would ensure a self-assessment of the companies has not been publicly available. Listing the components for a prescriptive purpose is exclusively relevant for MM-AND and MM-SLI, but neither contains information about them. Without the provision of improvement measures and a decision mechanism to weigh alternatives, the implementation of the prescriptive part cannot be guaranteed. This result is in line with the results by Pöppelbuß and Röglinger (2011) in 2011. Since then, an improvement of the degree to which the criteria have been met has not been observed.

In addition, both coders independently answered the question of whether the model is applicable by potential users in practice after a careful read of the article. The coders agree that MM-BER is the only one that can be transferred into practice. The model is understandable and published with essential information, and the model development is comprehensible in large parts. Assessment criteria for each element within each maturity level would be desirable. The descriptive purpose also slightly restricts the scope of application. According to unanimous opinion, MM-CHA, MM-FRO, and MM-SLI cannot be adopted since essential parts for application are not sufficiently described. These include, on the one hand, the lack of maturity levels in MM-FRO and, on the other hand, the lack of assessment methodology and criteria in MM-FRO and MM-SLI, as well as a controversial assessment methodology in MM-CHA. For MM-AND, some disagreement exists between the two coders. As before, an assessment methodology to evaluate the company's status quo is missing. However, the decisive factor for the decision is that the article does not state clearly what the maturity levels are that companies pass through ("Is it even necessary to reach maturity level 5 in the entrepreneurial stage to grow?").

Publication outlet of the article	**Reuters Index**	**H-index**	**SJR**
International Journal of Information Management	7.3	91	1.7
International Journal of Organizational Analysis	1.2	19	0.4
Iranian Journal of Management Studies (not listed)	0	0	0
Journal of Economics and Management (not listed)	0	0	0
Ø publication outlets	2.1	27.5	0.5

Table IV.4. Impact factors of the four released models (2015–2019)

The analysis of the publication outlets of these five articles draws a similar picture to the analysis in the second section. One was presented at a conference; the remaining four were published in journals with different impact factors (see Table IV.4). The Iranian Journal of Management Studies and the Journal of Economics and Management are not listed by SJR and, therefore, are rated with 0. Comparing the average values with those of the six articles from Tarhan et al. (2016) (Reuters Index: 3.9, H-index: 59.8, SJR index: 0.4), it can be seen that the Reuters Index and especially the H-index remain well below the values. This might lead to the conclusion that these journals can be classified as even weaker. Despite the slight improvement of SJR, all the values remain well below the comparative values of the subject categories (Top 50 journals). It should be noted that in recent years, only minor changes have taken place regarding the outlets. This finding underpins the reasoning that there is an urgent need for action to improve methodological transparency to achieve greater replicability of the results, to publish them in higher-quality journals, and thus to support the dissemination and application of the models in practice. Therefore, criteria that support authors in presenting the methodological transparency of BPMMs are indispensable.

IV.6 Conclusion

This research is motivated by the observation that in recent years, various maturity models have been published, but only a few are apparently applied in practice (Felch et al., 2019; Jamaluddin et al., 2010). A lack of reproducibility and replicability seems to be a possible reason. To justify this assumption, we analyzed the publication outlets of BPMMs that were released between 1990 and 2014. We find that BPMMs are mainly published in less-recognized journals. Against this background, the paper presents criteria for increasing the methodological transparency of BPMMs grouped by the three DSR segments, namely, environment, IS research, and knowledge base. Applying these criteria can help to increase the models' limited reproducibility and replicability. The derived set of criteria was tested on five recently published BPMMs. We find that basic model components are almost completely covered and that the models' purpose of use is stated. However, specific criteria in terms of descriptive and prescriptive purposes are not sufficiently addressed and therefore strongly influence BPMM applicability. A reasonable justification for the model development is usually provided. However, the situation is different with regard to transparency of development and evaluation processes. The recourse to procedure models, existing models and criteria for model evaluation or application is very rare. Because the replicability of the design/construct and the methodology are essential criteria for peer review processes of journals (Bornmann et al., 2008), the publication of the five models in less-recognized journals is not surprising.

Our proposed criteria constitute a first step to address this issue. They contribute to the knowledge base by (1) supporting researchers in implementing more methodological transparency by creating a solid and substantiated BPMM, (2) providing reviewers with a profound checklist to rely on for the evaluation of future submitted models, and (3) comparing existing BPMMs and uncovering their shortcomings. We are convinced that the practice will also benefit from more substantiated and transparent models. By describing the essential model criteria, the selection of suitable BPMMs will be facilitated for the decision makers and will enable an effective and efficient model application in the company. In addition, increased reproducibility and reproducibility of the research can support gradual model improvements.

A major limitation of this paper is that the criteria have been derived exclusively from the literature. To increase the explanatory power of the criteria, we are currently planning to evaluate them, e.g., as part of expert interviews and surveys of model users. Within this context, it can be clarified which criteria are to be classified as mandatory and optional and if main criteria are missing. The proof of the criteria's usefulness can solely be provided by a long-term study, which puts the degree of criteria employment in relation to the quality of the publication outlets. Second, the number of models analyzed is low. In the near future, it is planned to examine further maturity models from different domains. Third, it is necessary to confirm the statement that BPMMs are only rarely adopted in practice by an empirical study, e.g., a survey or interviews in companies. In addition to the lack of reproducibility and replicability, there may be other reasons for not applying BPMMs in practice. Tarhan et al. (2016) and van Looy (2014) have expressed initial doubts about the quality and usefulness of BPMMs. Furthermore, Becker et al. (2009) criticize the insufficient documentation of maturity models. Other reasons could be that BPMMs are not sufficiently specified or lack customizability, as is the case with Industry 4.0 maturity models (Felch et al., 2019). Therefore, the empirical study should also focus on the purpose of using, as well as reasons for not applying a BPMM to meet the users' requirements in future BPMMs. Despite these limitations, the criteria can motivate a better theoretical foundation of future BPMMs and thus achieve wider acceptance. In addition, the criteria provide a new direction for model development and can be considered a starting point for developing a general theory about maturity models.

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Article V. Advancing the Quality of Business Process Maturity Models

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Abstract. Over the years, academia has developed and published various business process maturity models (BPMMs) that supposedly assist companies in systematically identifying, evaluating, and improving their capabilities. However, as several authors have previously indicated, the quantity of the published models may not always meet the required quality. To examine whether these views are justified, this paper performs a publication outlet and citation analysis for articles from 1990 to 2019. The results show that BPMMs are predominantly published in less-recognized journals and are less frequently cited than other works in the domain of business process management. This finding highlights the need for improvement and motivates the derivation of criteria that help to enhance the quality of BPMMs. The presented criteria are particularly valuable for (1) researchers seeking to publish more transparent and replicable BPMMs and (2) reviewers deciding whether the models should be published. Eventually, they will likewise facilitate model application and dissemination in business practice.

Keywords. Business Process · Maturity Model · Publication Outlets · Citation Analysis · Quality · Criteria

V.1 Introduction

Due to continuously changing market conditions and economic uncertainty, companies constantly strive to sustain and enhance their competitive advantages. Therefore, they are always under pressure to evolve in line with the growing market dynamics and continuously improve their underlying business processes (de Bruin et al., 2005; Felch et al., 2019; Lee et al., 2007; van Looy, 2014). Business process maturity models (BPMMs) can contribute to this organizational transformation and capability renewal by "[...] determining the organization's status, deriving improvement measures, and conducting cross-company comparisons" (Felch & Asdecker, 2020, p. 368). In response to practical interest, the number of publications has steadily increased over recent years (Bley, 2021; Pereira & Serrano, 2020; Raber et al., 2016). However, more than a decade ago, de Bruin and Rosemann (2007, p. 644) already noted that "[...] a number of available models appear to be 'power-point deep' in that they are proprietary in nature, have not been rigorously developed and tested, and are not supported by tools that enable them to be applied within a wide range of organizations". Later, Pöppelbuß and Röglinger (2011, p. 1) critically reflected on this and questioned "[...] whether high quantity goes along with high quality". In a similar vein, van Looy (2014, p. 18) pointed out that "[...] the many existing BPMMs are assumed to differ in quality". In a more structured attempt, Tarhan et al. (2016) provided a systematic literature review focusing on publications from 1990 to 2014. In line with the previous observations, they expressed doubts about the quality and usefulness of several reviewed BPMMs. Felch and Asdecker (2020) complemented their analysis for 2015–2019 and concluded that most research gaps identified by Tarhan et al. (2016) have been neglected thus far. Doubts about the quality of BPMMs remain. To substantiate whether the criticism of inferior BPMMs is justified, we examine publications in the 1990–2019 period using two quality proxies. Accordingly, the first research question is as follows:

(1) Which publication outlets released the BPMM articles, and how frequently have they been cited to date?

The analysis shows that the papers are predominantly released in less-recognized journals and are cited less frequently than other business process management (BPM) articles. Although the reasons may be manifold, the low reputation of the publication outlets and the limited number of citations suggest that the maturity models developed do not consistently meet the needs of reviewers, researchers, and users. This issue leads to the following second research question:

(2) Which criteria should be considered to enhance the quality of BPMM publications?

The study at hand reinforces the real-world problem of the previously published article by Felch and Asdecker (2020) using two quality proxies. Based on the design science research (DSR) paradigm, the existing criteria for quality assurance are further subjected to both an ex ante and a more comprehensive ex post evaluation. The present study complements the efforts of Felch and Asdecker (2020) to advance maturity models and points to the need for both model developers and reviewers to pay more attention to the quality of future models. The article contributes to the BPM literature by providing better guidance to (1) researchers who try to advance their research transparency to create more solid and replicable BPMMs and (2) reviewers who decide whether submitted maturity models are to be published. Eventually, both will lay the foundation for more useful BPMMs that can be applied in business practice.

The remainder of the article is structured as follows: The next chapter outlines the results of the publication outlet and citation analysis. This is followed by the derivation and evaluation of criteria for the publication of transparent and substantiated BPMMs that are derived and evaluated while methodologically drawing on the DSR paradigm. This work concludes with a summary of the main findings, derived implications, and limitations.

V.2 Analyzing Quality Indications of BPMM Studies and Identifying the Problem

When publishing an article, BPMM authors pay particular attention to the publication outlet's level of recognition. It most likely affects the dissemination of the work in the professional community (e.g., experts with a scientific background, consultants) and thus determines the number of model applications. This gives scholars an incentive to submit their models to the most recognized journals. At the same time, those journals act as gatekeepers ensuring that scientific and methodological standards are met. Hence, if the previously postulated criticism of lower quality is valid, this should become apparent in the publication outlets.

According to the reviews by Tarhan et al. (2016) and Felch and Asdecker (2020), a total of 61+69=130 BPMM articles were released between 1990 and 2019. 64 of those were published in academic journals. To determine a quality indicator for these outlets (cf. Garfield, 2006), we refer to three impact factors: (1) the index by Thomson Reuters (Reuters Index) (Web of Science Group), (2) the H Index by Hirsch (2005), and (3) the SCImago Journal Rank (SJR) indicator (SJR - SCImago Journal & Country Rank). Generally, the lower the impact factor, the lower the journal's ranking and reputation. The impact factor data are retrieved from SJR – SCImago Journal & Country Rank (www.scimagojr.com, as of January 2020). An impact factor of 0 was assigned to journals that are not listed in SJR (e.g., Journal of Economics and Management). Apart from analyzing all 64 publications, several subcategories related to model development and application in general were considered (adopted from Tarhan et al. (2016)). We calculated the mean values of the impact factors from all 64 publications and within the subcategories (see Table V.1, adapted from Felch and Asdecker (2020)). Considering all 64 articles (1990–2019), the average Reuters Index is 2.4, the average H Index is 43.6, and the average SJR index is 0.5.

Article classification	# Articles	Reuters Index	H Index	SJR
Release	10	3.2	46.9	0.5
Description	15	2.2	40.6	0.6
Empirical study on application	21	2.5	39.5	0.6
Development	12	2.9	47.7	0.4
Application	16	2.8	44.1	0.6
All articles (1990–2019)	64	2.4	43.6	0.5

Table V.1. Average impact factors of BPMM research (1990–2019)

The influence and relevance can be assessed by comparing the mean values with the average impact factor of the journals' selected overarching subject categories. The average impact factors are calculated after identifying the top 50 journals using the SJR website (see Table V.2, adapted from Felch and Asdecker (2020)). To allow for a sound assessment, the lowest and highest values of each index across all subject categories and across the selected overarching subject categories are also listed in Table V.2. The juxtaposition of Tables 1 and 2 reveals that the highest values of the considered article categories (see Table V.1; Reuters Index: 3.2 for 'release' publications, H Index: 47.7 for 'development' publications, SJR: 0.6 for multiple categories) only reach the lowest mean values of the selected subject categories (see Table V.2; Reuters Index: 2.8, H Index: 47.4, SJR: 1.0 in each case for 'Management Information Systems') and are well below their average values (Ø subject categories, as shown in Table V.2). Despite the time-dependent impact factors, the comparison illustrates that articles about BPMMs are published in less-recognized journals with limited relevance to the scientific community (cf. Felch & Asdecker, 2020).

Subject category according to SJR	Reuters Index	H Index	SJR
Range incl. all subject categories	{0;206.9}	{0;1096}	{0.1;72.6}
Range incl. 12 selected subject categories	{0;19.4}	{0;335}	{0.1;30.5}
Business and International Management	5.3	103.1	3.1
Business, Management and Accounting (misc.)	3.7	84.5	1.9
Computer Science Applications	7.4	144.6	2.6
Economics and Econometrics	5.6	137.2	7.4
Industrial and Manufacturing Engineering	5.2	101.8	1.8
Information Systems	6.0	93.3	1.8
Information Systems and Management	3.5	57.9	1.1
Management Information Systems	2.8	47.4	1.0
Management of Technology and Innovation	4.7	98.4	2.5
Management Science and Operations Research	3.7	85.2	1.8
Software	6.8	124.3	2.2
Strategy and Management	5.6	123.7	3.5
Ø Subject categories	5.0	100.1	2.6

Table V.2. Average impact factors of the top 50 journals in selected subject categories

In addition, a citation analysis is performed, as the number of citations is an essential indicator of quality and impact on the scientific community (Bornmann, 2011; Meho, 2007; Straub & Anderson, 2010). Accordingly, it can be assumed that there is a "[...] high positive correlation between the number of citations which a particular document [...] receives and the quality of that document [...]" (Smith, 1981, p. 87). Thus, in the long run, high-quality articles are appreciated by the community and cited more often, while weaker articles are referenced less frequently (Straub, 2008).

The data for the analysis are retrieved via the Scopus database (as of May 2021) and adjusted for duplicates and self-citations, i.e., if the author(s) of the original article appears as the author(s) on the citing articles ('citable docs'). The citation count of unlisted articles is rated 0. Average citations per year are calculated to account for the different publication dates and allow for better comparability (see Table V.3).

Article classification	Ø Citable docs	Ø Citable docs/year	No. of papers with citations		
			<10	10–99	≥100
Release	35.3	2.5	16	7	2
Description	8.3	1.0	20	7	0
Empirical study on application	14.7	1.4	34	11	2
Development	37.0	2.7	15	10	2
Application	10.7	1.3	24	8	1
All articles (1990–2019)	24.6	2.3	87	34	9

Table V.3. Citation statistics from BPMM research (1990–2019)

On average, each of the 130 articles identified in the two complementing literature reviews of Tarhan et al. (2016) and Felch and Asdecker (2020) was cited nearly 25 times (see Table V.3). However, only 7 % of the articles (9 out of 130) have more than 100 citations, which, according to Recker and Mendling (2016), can be considered "well-cited". Among those nine well-cited articles are five meta-analyses (de Bruin et al., 2005, 294 citations; Rosemann & vom Brocke, 2010, 272 citations; Wendler, 2012, 232 citations; Röglinger et al., 2012, 208 citations; Pöppelbuß & Röglinger, 2011, 130 citations), two BPMM releases (Hammer, 2007, 324 citations; Rosemann & de Bruin, 2005, 217 citations), one BPMM application (Škrinjar et al., 2008, 138 citations), and one BPMM validation (Škrinjar & Trkman, 2013, 114 citations). Three are published in conference proceedings, and one article is published in a book. The mean values of the impact factors of the five journal articles (Reuters Index: 6.1, H Index: 96.8, SJR: 0.7) reach the mean values of the selected subject categories (see Table V.2) and imply that those are published in higher-quality journals.

The vast majority (87 out of 130) have fewer than ten citations thus far and are therefore classified as low-cited. Articles categorized as 'release' or 'development' are, on average, cited more often than articles with description or application purposes. However, the mean values of these two categories – 'release' and 'development' – are strongly positively influenced by the two well-cited publications from Hammer (2007) and Rosemann and de Bruin (2005), which is a typical problem of mean citation counts (Bornmann & Daniel, 2008). In a similar citation analysis of BPM papers with no specific focus on maturity models, Recker and Mendling (2016) showed that papers published between 2003 and 2014 have been cited 39.4 times on average, with 35.8 % being cited less than ten times, 55.2 % cited between 10 and 99 times and 9.0 % cited more than 100 times. The absolute numbers and the comparison with Recker and Mendling (2016) imply that the published BPMM papers are rarely cited comparatively. Together with the publication outlet analysis, the following picture emerges: BPMM studies are released in less-recognized outlets and are rarely cited, even less frequently than other BPM articles. Both findings reinforce several authors who previously pointed out the lack of BPMM quality but did not perform a thorough analysis (e.g., van Looy, 2014; de Bruin & Rosemann, 2007; Pöppelbuß & Röglinger, 2011).

This raises the question of "why" and "what" can be done about it. Previously voiced criticisms of maturity models include inadequate methodology (e.g., Rosemann & de Bruin, 2005; Marx et al., 2012; de Carolis et al., 2017; Pereira & Serrano, 2020) and insufficient model documentation (e.g., Becker et al., 2009; Maier et al., 2012; Pöppelbuß et al., 2011; van Looy et al., 2013; Albliwi et al., 2014), which can cause a lack of transparency, replicability, and reproducibility. In addition, relevance to theory and practice – represented by significance or usefulness (Cachon et al., 2020; Gallien et al., 2016) – is essential but sometimes lacking (e.g., de Bruin & Rosemann, 2007; Patas et al., 2013; van Looy et al., 2013). Taking a broader perspective, these points of criticism refer to the most common scientific principles that are decisive criteria of peer-review processes: use of adequate methods, appropriate and comprehensible documentation, and relevance of the research for academia and practice (Canadian Institutes of Health Research, Natural Sciences and Engineering Research, Social Sciences and Humanities Research Council of Canada, 2016; Deutsche Forschungsgemeinschaft, 2019; National Academy of Sciences, 2009; UK Research Integrity Office, 2009). Therefore, the results of the publication outlet and citation analysis are hardly surprising and appear reasonable.

This leads to the second research question. Starting with problem identification, it is necessary to develop propositions that will help advance the status quo. To date, the maturity model literature recognizes the importance of deriving quality criteria (van Looy et al., 2013; Wendler, 2012) but has not delivered any domain-specific viable suggestions. This study makes such an attempt to increase support for authors, reviewers, and editors. The following section describes the process of deriving suitable criteria that help enhance the quality of BPMMs.

V.3 Deriving Criteria to Improve the Quality of BPMMs

Methodologically, this part of the study draws on design science research (DSR), which provides a structured approach to solving real-world problems. The previously described problem of poor quality maturity models is rooted in academia. Nevertheless, it has direct implications for business practice, as insufficient quality limits the models' usefulness and applicability to other researchers, consultants, and/or industry experts. This hinders continuous improvement processes aimed at enhancing organizational performance and the ability to remain competitive. Therefore, the goal is to develop an artifact that reduces the real-world problem of quality assurance. March and Smith (1995) distinguished four kinds of artifacts, namely, (1) constructs, (2) models, (3) methods, and (4) instantiations. The pursued quality criteria for BPMMs represent a method artifact. Similar to the DSR paradigm, this study focuses on "knowledge-for-design" (Alturki et al., 2013; van Aken, 2005, p. 22). Thus, the proactive and episodic approach seems suitable (Baskerville et al., 2009; Goes, 2014; Hevner et al., 2004). Typically, DSR comprises two primary and closely interrelated activities: (1) building and (2) evaluating (Cronholm & Göbel, 2019; Hevner et al., 2004; March & Smith, 1995; Vaishnavi et al., 2004). Sein et al. (2011) reflected critically on the strict sequence of these two activities and concluded that this contradicts the underlying concept and the emergent nature of this research method in particular. They stressed the importance of the interaction between both activities to reflect the artifact's progress and to be able to introduce changes at an early stage. Therefore, Sonnenberg and vom Brocke (2012a, 2012b) expanded the DSR process to include early ex ante evaluations in addition to the usual ex post evaluation, which contributes to an ongoing evaluation and refinement of the artifact (Sturm & Sunyaev, 2019). Each DSR activity is complemented by an evaluation step and thus results in six activities before the suggested artifact is applied in practice to show its usefulness (see Figure V.1, adapted from Sonnenberg and vom Brocke (2012b)).

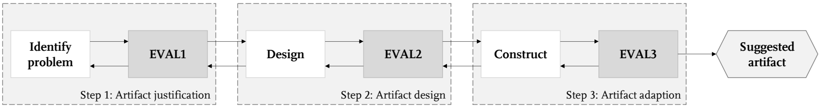

Figure V.1. Applied DSR activities

The first step, problem identification and justifying the meaningful real-world problem ('EVAL1'), has already been performed. To ensure the pursued higher-quality assurance, the second step involves the derivation of useful criteria. Subsequently, the preliminary artifact is presented at a research-related conference to evaluate it for completeness, comprehensiveness, and level of detail ('EVAL2'). In step 3, suggested changes are included in the preliminary artifact. The adapted artifact is then again introduced to three experts for evaluation before the artifact's applicability is demonstrated using structured content analysis ('EVAL3'). In the following subchapters, steps 2 and 3 are described in detail before concluding the process with the developed artifact.

Step 2: Artifact Design and Evaluation (EVAL2)

Before designing the artifact, it was first ensured that no other publication could sufficiently answer the second research question. The work most similar to this research is from Pöppelbuß and Röglinger (2011). They presented a total of nine design principles, consisting of four basic design principles, two design principles for a descriptive purpose of use, and three design principles for a prescriptive purpose of use. While those principles are a good starting point to improve the documentation of BPMMs, they only focus on a model's purpose and do not specifically consider other important criteria of model development.

The existing research gap motivated and justified a literature search in the context of business process management (BPM) to identify publications that contribute to the qualitative issues under investigation (cf. Alturki et al., 2011). Therefore, the search terms 'maturity model', 'capability model', 'design science', 'transparency', 'business process management', 'business process', 'business performance', 'empiric*', and 'valid*' were applied in four databases, namely, EBSCO, Google Scholar, ScienceDirect, and Web of Science. The following selection criteria were used for the initial search results. First, duplicates were removed. Second, only English academic papers in journals, conference proceedings, and books were considered. Nonacademic publications, such as white papers, opinion pieces, student papers, and PowerPoint presentations, were excluded. Third, articles that were not within the scope of this study were omitted, e.g., those that dealt with maturity models only in the abstract or referred to a specific model. After reviewing the titles, abstracts, and keywords, we screened the remaining articles based on their full text. The focus was on identifying papers that explicitly referred to criteria that improve the quality of BPMM publications. A total of 34 relevant articles remained (see Appendix A). After reading those papers, we synthesized the literature by discussing relevant aspects among the research team as suggested by Webster and Watson (2002). Their concept-centric approach resulted in three dimensions, which reflect aspects of the scientific principles and criteria of the peer-review process: (1) design methodology, (2) model documentation, and (3) model content scope.

Design methodology. To achieve scientific rigor and design a well-grounded model, authors need to choose an adequate methodology. In the past, several researchers have published procedure models with standardized steps to support a purposeful design (e.g., de Bruin et al., 2005; Becker et al., 2009; Maier et al., 2012; Mettler, 2009; see Table V.4, adapted from Felch and Asdecker (2020)). To develop the architecture as well as the content of the model, explorative research methods, such as focus groups and Delphi studies, should be considered aside from a literature review (Becker et al., 2009; de Bruin et al., 2005; Lahrmann et al., 2010; van Steenbergen et al., 2010). In contrast, either qualitative methods (e.g., expert interviews) or demonstrations and experiments with the prototype should be used to improve the actual model (Becker et al., 2009; Helgesson et al., 2012; Sonnenberg & vom Brocke, 2012a). Before model dissemination takes place in practice, it should be validated. In addition to qualitative methods, quantitative methods, e.g., surveys, can be used for data collection (Mettler, 2010; Sonnenberg & vom Brocke, 2012a; Wendler, 2012).

Unit of analysis	Appropriate approaches to ensure BPMM design methodology quality
Procedure model	E.g., Becker et al. (2009), de Bruin et al. (2005), Maier et al. (2012), Mettler (2010), van Steenbergen et al. (2010)
Development method	Literature review, case study, Delphi study, focus group
Evaluation method	Demonstration with prototype, experiment with prototype or system, benchmarking, survey, expert interview, focus group
Application method	Case study, field experiment, survey, expert interview, focus group

Table V.4. Preliminary quality criteria for the dimension 'design methodology'

Model documentation. Since the application and dissemination of models in business practice require high-quality documentation, it is crucial to ensure maximum transparency for the model stakeholders, such as the users or assessors involved. This includes the description of the application-specific purpose that is pursued with the maturity model (Pöppelbuß & Röglinger, 2011). Thus, maturity models can be an instrument to determine the status of the organization (descriptive), to derive improvement measures (prescriptive), and to perform internal or cross-company comparisons (comparative) (see Table V.5, adapted from Felch and Asdecker (2020)). To increase replicability, dimensions and elements, these particularly include the capabilities that the organization should achieve at each maturity level (Fraser et al., 2002; Maier et al., 2012; Pöppelbuß & Röglinger, 2011). Furthermore, it is recommended to provide the assessment criteria and methodology for descriptive models (Pöppelbuß & Röglinger, 2011). In the case of publishing prescriptive models, the mentioned criteria should be supplemented by further components, e.g., improvement measures, decision criteria, and methodology (Pöppelbuß & Röglinger, 2011).

It is worth mentioning that the two dimensions – 'design methodology' and 'model documentation' – are generic. In contrast, the dimension 'model content scope' reflects the particularities of the research area (domain-specific) and thus has to be explicitly derived concerning the field of application. To effectively guide organizational decisions, it is recommended that authors solely rely on empirical evidence when defining their model content (Baldridge et al., 2004; Gallien et al., 2016; Gallien & Scheller-Wolf, 2013; Nicolai & Seidl, 2010; Toffel, 2016).

Unit of analysis	Necessary content to ensure BPMM documentation quality
Intended model purpose	Descriptive, prescriptive, comparative
Basic components of the model	Number of levels, descriptor for each level, generic description of the characteristics of each level, number of dimensions, number of elements for each process area, description of each activity as it might be performed at each maturity level
Components of descriptive maturity models	Intersubjectively verifiable criteria for each maturity level and level of granularity, target group-oriented assessment methodology
Components of prescriptive maturity models	Improvement measures for each maturity level and level of granularity, decision calculus for selecting improvement measures, target group-oriented decision methodology

Table V.5. Preliminary quality criteria for the dimension 'model documentation'

With regard to BPM, we, therefore, focused on BPM factors that affect organizational performance. To be considered a relevant factor, at least two independent studies had to validate the influence empirically. To identify these factors, the search terms 'business process management', 'business process', 'business performance', 'empiric*', and 'valid*' were used in four databases (EBSCO, Google Scholar, ScienceDirect, and Web of Science). Subsequently, the search results were refined based on the previously used selection criteria (removal of duplicates, English academic papers, and fit of scope) and abstract and full-text analysis. We were able to narrow the results to 22 studies: Babic-Hodovic et al. (2012), Bronzo et al. (2013), Diller and Ivens (2006), Forsberg et al. (1999), Gustafsson et al. (2003), Hellström and Eriksson (2013), Hernaus et al. (2012), Ittner and Larcker (1997), Kohlbacher and Gruenwald (2011a), Kohlbacher and Gruenwald (2011b), Kohlbacher and Reijers (2013), Kumar et al. (2010), Leyer et al. (2017), McCormack (2001), McCormack and Johnson (2001), Milanović Glavan and Bosilj-Vukšić (2017), Movahedi et al. (2016), Münstermann et al. (2010), Münstermann et al. (2009), L. Nilsson et al. (2001), Pradabwong et al. (2017), Škrinjar et al. (2008). Then, the researchers coded the factors that have a significant impact on organizational performance. In total, the researchers identified 167 such factors. Afterward, duplicates were removed, and only those factors whose influence was empirically confirmed in two independent studies, i.e., in two different samples, were grouped thematically. The research team discussed the classification in several rounds to eliminate inconsistencies. The following factors can be derived exemplarily for the research area 'business process management'. It should be noted that these factors may change over time due to new findings from future publications (e.g., new empirically confirmed cause-and-effect relationships). Therefore, it should be regularly checked whether outdated factors must be deleted and new ones included.

Model content scope. In total, five relevant constructs were identified: (1) organization, (2) supply chain integration, (3) process, (4) IT, and (5) employees (see Table V.6, adapted from Felch and Asdecker (2020)). First, the construct 'organization' aims at the organizational structure aligned with the process perspective (e.g., Bronzo et al., 2013; Kohlbacher & Reijers, 2013). The alignment of the business processes is in line with the organization's strategic focus, whereas the corporate culture encourages teamwork, willingness to change, and a cooperative management style (e.g., Milanović Glavan & Bosilj-Vukšić, 2017; Pradabwong et al., 2017). 'Supply chain integration' focuses on the relationships and interactions between companies and their suppliers as well as the orientation toward customer needs. Collaboration between suppliers and businesses is primarily about joint planning, forecasting, and process improvement to increase customer satisfaction (e.g., Bronzo et al., 2013; Milanović Glavan & Bosilj-Vukšić, 2017). The third construct 'process' concerns managing and improving business processes. This implies, among other things, the specification of the persons responsible for the process (e.g., Ittner & Larcker, 1997; Kohlbacher & Gruenwald, 2011b). To enable a purposeful design, evaluation, and continuous improvement of processes, it is crucial to define and document them in advance (e.g., McCormack, 2001; Movahedi et al., 2016; L. Nilsson et al., 2001; Škrinjar et al., 2008). The construct 'IT' addresses the renewal and implementation of appropriate IT systems within and across companies (e.g., Diller & Ivens, 2006; Pradabwong et al., 2017). The construct 'employees' relates to the recruitment, involvement, and development of the organization's workforces (e.g., Bronzo et al., 2013; Ittner & Larcker, 1997; Pradabwong et al., 2017). Another critical aspect is the ongoing dialogue and discussion between employees and management (e.g., Hernaus et al., 2012; Kumar et al., 2010). All these factors constitute capabilities with empirical evidence of their impact on business performance. Consequently, BPMMs should refer to one or more of these constructs.

Unit of analysis	Relevant scope to ensure BPMM content quality
Organization	Organizational structure, strategic alignment, culture
Supply chain integration	Supplier orientation, customer orientation
Process	Process focus/orientation, process owner, definition and documentation of processes and process measurement, design of processes, measurement of processes, improvement of processes
IT	Support of IT tools
Employees	Design of jobs and workplace, employee development, employee involvement and motivation, employee information exchange

Table V.6. Preliminary quality criteria for the dimension 'model content scope'

After designing the preliminary artifact, it had to be evaluated to verify whether it would solve the identified problem ('EVAL2') (Sonnenberg & vom Brocke, 2012a, 2012b). This step aims at strengthening the artifact's validity and ensuring the rigor of the design process. Moreover, it is intended to avoid "[...] devoting a significant amount of time to building insignificant solutions to practical problems" (Sonnenberg & vom Brocke, 2012b, p. 381) and therefore pursues a self-improvement function. According to Sonnenberg and vom Brocke (2012a), purposeful evaluation criteria include ‘suitability to the stated problem’, ‘comprehensibility’, ‘level of detail’, and ‘completeness’.

For evaluation, the preliminary artifact was demonstrated at the 18th International Conference on Business Process Management (BPM 2020) (see Felch & Asdecker, 2020), which allowed the communication of the achieved results to the scientific community (cf. van Looy et al., 2013). Conferences as a particular evaluation tool are appropriate, as they provide rapid feedback and critical evaluation through double-blind review and close interaction with peers during the conference itself. The selection of the conference was based on the content-related consistency with the research question to provide rich information. In addition, both members of the conference steering committee and the track chairs are highly respected experts in their field. They have many years of experience with the research topic (as model designers and reviewers). Overall, the preliminary artifact received positive feedback concerning the evaluation criteria ‘suitability to the stated problem’, ‘comprehensibility’, and the artifact’s ‘level of detail’. However, a discussion arose concerning the presented framework’s ‘completeness’. The fundamental idea of BPM and especially of BPM lifecycles aims at the continuous development and improvement of capabilities given the changing customer needs, technologies, and permanent competitive pressure (Dumas et al., 2018; Mendling, 2008; van der Aalst, 2013; Voglhofer & Rinderle-Ma, 2020; Willaert et al., 2007). Thus, the following question arose: To what extent can BPMMs adapt, that is, do they have the ability to evolve? The discussion on evolutionary ability referred to the timeframe aimed at a sustained accuracy and relevance of the published models and thus, in the long term, greater appreciation by the scientific and professional community, which is therefore considered an important quality criterion. This idea was not reflected in the preliminary artifact, which led to the next step – the adaption of the artifact to meet the criterion ‘completeness’.

Step 3: Artifact Construction and Evaluation (EVAL3)

In general, the step 'construct' is about refining the preliminary artifact based on the feedback received (Sonnenberg & vom Brocke, 2012a, 2012b). It requires a justification of the changes to be made and the actual adoption of the artifact, i.e., the addition of suitable criteria. Once again, referring to the literature, some authors point toward the need for adjustment, often termed maintenance, without further specification (Becker et al., 2009; de Bruin et al., 2005; Lahrmann & Marx, 2010; Maier et al., 2012). Otherwise, maturity models are at risk of becoming outdated or invalid "[...] because of changing conditions, technological progress or new scientific insights" (Becker et al., 2009, p. 219). Furthermore, Maier et al. (2012, p. 152) stated that "[...] domain knowledge and understanding broadens and deepens" over time. Thus, if maturity models do not contain dynamic elements that allow them to adjust to new circumstances, they are merely a static representation of their developmental phase and, therefore, only applicable for a short period. Thus, a continuous adjustment is necessary for lasting model relevance (Becker et al., 2009; de Bruin et al., 2005; Lahrmann & Marx, 2010; Maier et al., 2012; Mettler, 2009), which should already be considered early on in the model design phase (Mettler, 2010). Acknowledging the relevance, we added a fourth BPMM quality dimension due to the evaluation step – a model's evolutionary ability. Similar to the dimensions 'design methodology' and 'model documentation', the additional dimension is generic. Mettler (2009, 2010, 2011) suggested criteria that will be used to operationalize a model's evolutionary ability.

Evolutionary ability. Since evolution is defined as "[...] a gradual process in which something changes into a different and more complex or better form" (Russell et al., 2010, p. 5), it is crucial to determine which parts of the maturity model should be changed. Mettler (2009, 2010, 2011) suggested that the underlying meta-model of the maturity model (form) or the assessment/decision methodology (functioning) can be modified (see Table V.7). To successfully transform the model, the parameters of change need to be addressed in advance. The actual changes depend on authorized individuals (initiators) to revise the model components

(Mettler, 2009, 2010, 2011). Furthermore, depending on the available resources, the frequency with which the maturity model needs to be adjusted in the future should be considered (frequency) (Mettler, 2009, 2010, 2011).

Unit of analysis	Evolutionary elements to ensure BPMM long-term quality
Model components	Form, functioning
Parameters of change	Frequency of change, initiator of change

Table V.7. Preliminary quality criteria for the dimension 'evolutionary ability'

The artifact adaption is followed by another evaluation activity ('EVAL3') where the constructed artifact "[...] should be evaluated regarding their applicability" (Sonnenberg & vom Brocke, 2012b, p. 395). This phase mainly involves the application in an artificial setting (Sonnenberg & vom Brocke, 2012b). Beforehand, the adapted artifact was presented to three researchers of the maturity model community, who have been successfully publishing in the domain for many years. They provided additional positive feedback regarding the completeness and comprehensibility of the artifact.

To demonstrate the applicability of the criteria and further substantiate the impression that many BPMM papers suffer from qualitative weaknesses, we analyzed the BPMMs released between 1990 and 2019 using the derived criteria framework. In total, the analysis comprised 25 BPMMs (classified as 'released' according to Tarhan et al. (2016) and Felch and Asdecker (2020), see Appendices B and C) that were evaluated by a structured content analysis in line with Krippendorff (2019). Each article represented a unit of analysis. The material was first screened by coder A (who developed the framework) using the codebook. To avoid potential errors in the criteria application and ensure high reliability of the results, a second coder (coder B with several years of experience with maturity models) examined the same articles independently. Alternatives not previously considered in the framework but mentioned in the analyzed articles were initially coded as 'others'. Later, those codes were used to complement the framework further. The results of the coding processes were independently documented in MAXQDA. Both files were merged, and the coded sections were compared against each other. The intercoder reliability (# of agreements / # of total codes) was 84.7 %. According to Neuendorf (2002, p. 143), this value can be considered reliable. All disagreements were discussed in detail before a consensus decision, and the data were finally interpreted.

The analysis includes articles that describe the initial development of BPMMs as well as subsequent articles that refine an existing BPMM, in which case each is coded separately (cf. Heinze & Geers, 2009; Jochem et al., 2011; Rosemann et al., 2004; Rosemann & de Bruin, 2005). Due to the almost complete textual consistency of publications (Rohloff, 2009a, 2009b, 2009c, 2010), only the most detailed article (Rohloff, 2010, incl. supplementary electronic material) is included in the analysis. The detailed results can be found in Appendix D. In the following, the most important results regarding the four derived dimensions, (1) design methodology, (2) model documentation, (3) model content scope, and (4) evolutionary ability, are presented. First, the design methodology dimension consists of four units of analysis: (a) procedure model, (b) development method, (c) evaluation method, and (d) application method.

- *Procedure model:* Only two BPMMs refer to standardized development procedures (Berger et al., 2018; Sliż, 2018). In addition, Zwicker et al. (2010) interpret a BPMM as an artifact and hence draw on the DSR paradigm.
- *Development method:* Authors mainly rely on existing literature to create new models (n=17). Eight BPMMs choose explorative methods, such as a case study (n=2) or a Delphi method (n=2). Other methods include external feedback from practitioners (n=5) or interviews (n=2). Only the contribution by de Bruin and Rosemann (2007) uses multiple methods to derive the dimensions of their BPMM.

- *Evaluation method:* A small number of articles (n=8) report on the evaluation of BPMMs. They mainly apply case studies within companies (n=5) to ensure comprehensibility and completeness. All recent models (2015–2019) are not evaluated. It remains unclear whether an evaluation took place or whether the evaluation is simply not described. The situation is slightly better regarding the application of BPMMs in practice.
- *Application method:* Five articles published between 1990 and 2014 document an application. However, a positive trend can be seen (n=3 between 2015 and 2019). To date, only case studies (n=6), surveys (n=2), and interviews (n=1) have been adopted.

Second, the dimension 'model documentation' also contains four units of analysis: (a) model purpose, (b) basic components of the model, (c) components of descriptive models, and (d) components of prescriptive models.

- *Model purpose:* In total, 19 models pursue a descriptive purpose, of which 14 and 6 models are additionally assigned a prescriptive or comparative purpose. Three models do not inform readers about their intended purpose (de Bruin & Rosemann, 2007; Škrinjar et al., 2006; Willaert et al., 2007).
- *Basic components:* The vast majority of articles describe the basic components, comprising the number of maturity levels (n=17), the descriptors for each level (n=17), and the number of dimensions (n=21) and elements for each process area (n=15). Despite the relevance of the criterion 'description of each activity as it might be performed at each maturity level' for the model's applicability and dissemination in practice, almost all papers refrain from documenting it. Only two models fully meet this criterion (Hammer, 2007; Moradi-Moghadam et al., 2013). Two other BPMMs provide at least excerpts of the individual stages (Rohloff, 2010; Zwicker et al., 2010). All others lack information on how to access the complete BPMM.

- *Components of descriptive models:* More than half of the models with a descriptive purpose (n=15) contain further criteria, such as assessment criteria and methodology, but are not addressed to an appropriate degree (especially completeness).
- *Components of prescriptive models:* Articles that present a prescriptive model do not address the additional criteria required.

Third, the model content scope dimension includes five units of analysis: (a) organization, (b) supply chain integration, (c) process, (d) IT, and (e) employees.

- *Organization:* More than half of the BPMMs (n=13) address at most one factor of organizational structure, whereby 'strategic alignment' is referred to most frequently (n=7). It is striking that models with more than one organizational factor (n=9) always consider 'culture'.
- *Supply chain integration:* In total, eleven models neglect the relationships with suppliers and customers. When addressing the construct, either both factors (n=8) or exclusively 'customer orientation' (n=3) are included.
- *Process:* The factors 'measurement of processes' (n=17) and 'definition and documentation of processes and process measurement' (n=15) are almost omnipresent. In addition, the BPMMs by de Bruin and Rosemann (2007) and Chaghooshi et al. (2016) address all of the factors described. A total of four models omit the management and improvement of business processes entirely (Heinze & Geers, 2009; Jochem et al., 2011; Rosemann & de Bruin, 2005; Škrinjar et al., 2006).
- *IT:* Almost two-thirds of the models (n=15) deal with the setup and maintenance of IT systems within and across organizations.
- *Employees:* Just above one-third of the BPMMs (n=8) include two out of four relevant factors, whereas nine models contain none. Altogether, this construct is considered least often, particularly the factors 'design of jobs and workplace' (n=4) and 'employee information exchange' (n=6).

Fourth, the dimension ‘evolutionary ability’ comprises two units of analysis: (a) model components and (b) parameters of change.

- *Model components:* Only three articles state that the model content must be expanded (Froger et al., 2019; Jochem et al., 2011; Rosemann & de Bruin, 2005). No modifications regarding the underlying methodology are mentioned. Two other articles note that the refinement or extension of the model is planned without specifying the scope of changes (Lee et al., 2007; Zwicker et al., 2010). The remaining articles (n=17) do not inform the reader about future model redesigns.
- *Parameters of change:* Two of the three articles indicating that changes to the form are intended also specify the necessary parameters of change. Rosemann and de Bruin (2005) report that the end-users can change the model, whereas Froger et al. (2019) suggest a one-time adjustment. None of the articles considered all criteria.

Overall, some analyzed BPMMs create the impression that they have not been developed using a systematic and rigorous methodology. Furthermore, all lack access to comprehensive documentation that would ensure replicability, and self-assessments by users or assessors are also lacking. This emphasizes the need to improve transparency and relevance to ensure higher replicability and publish BPMMs in higher-quality journals. Contentwise, the available models appear to capture the most relevant factors that determine process success and, hence, business success. Nevertheless, several models referred to additional factors such as ‘management of financial resources’ and ‘management contract’. However, at least two independent papers providing a proven effect on an organization’s performance could not be identified in our literature search. It shows the importance of justifying the model’s scope and dimensions, which is done too rarely. Eventually, we found only a few models that consider their ability to adapt to changing conditions. This is unfortunate because it contributes to models becoming obsolete after some time and consequently losing their applicability. For this reason, future models should already consider this when creating the model. To conclude, the application of the derived criteria shows that the framework can identify current shortcomings and highlight the potential for improvement.

Finally, the analysis of the 'other' codes provided an impetus for further additions to the developed framework. Concerning the model development, the evaluation step ('EVAL3') revealed two more suitable methods: (1) external feedback from practitioners or (2) expert interviews. In addition, case studies are an appropriate evaluation method. Several methods can be applied within each research phase, i.e., collecting data for model development, evaluation, or application (cf. de Bruin & Rosemann, 2007), equivalent to a multi- or mixed-method approach. Furthermore, in addition to maturity model-specific procedures that can guide the BPMM design process, generic procedures (cf. Zwicker et al., 2010) were added to the framework. The developed and evaluated artifact is summarized in Table V.8 (partly adapted from Felch and Asdecker (2020)). As already noted, the domain-specific dimension 'model content scope' requires an individual derivation of the factors. Table V.8 shows the exemplary factors for the domain of 'business process management'.

	Dimension	Unit of analysis	Indicators to ensure BPMM quality
Generic	Design methodology	Research guiding methodology	Maturity model-specific procedure (e.g., Becker et al., 2009; de Bruin et al., 2005; Maier et al., 2012; Mettler, 2010; van Steenbergen et al., 2010), generic procedure (e.g., DSR paradigm)
		Development method	Literature review, case study, Delphi study, focus group, external feedback from practitioners, expert interviews
		Evaluation method	Demonstration with a prototype, experiment with prototype or system, benchmarking, survey, expert interview, focus group, case study
		Application method	Case study, field experiment, survey, expert interview, focus group
	Model documentation	Intended model purpose	Descriptive, prescriptive, comparative
		Basic components of the model	Number of levels, descriptor for each level, generic description of the characteristics of each level, number of dimensions, number of elements for each process area, description of each activity as it might be performed at each maturity level
		Components of descriptive models	Intersubjectively verifiable criteria for each maturity level and level of granularity, target group-oriented assessment methodology

	Dimension	Unit of analysis	Indicators to ensure BPMM quality
		Components of prescriptive models	Improvement measures for each maturity level and level of granularity, decision calculus for selecting improvement measures, target group-oriented decision methodology
	Evolutionary ability	Model components	Form, functioning
		Parameters of change	Frequency of change, initiator of change
Domain-specific	Model content scope	Organization	Organizational structure, strategic alignment, culture
		Supply chain integration	Supplier orientation, customer orientation
		Process	Process focus/orientation, process owner, definition and documentation of processes and process measurement, design of processes, measurement of processes, improvement of processes
		IT	Support of IT-tools
		Employees	Design of jobs and workplace, employee development, employee involvement and motivation, employee information exchange

Table V.8. Criteria for quality assurance of BPMM publications

V.4 Conclusion and Outlook

Apart from the design and publication of many BPMMs in response to ever-expanding practical interest, doubts about the quality of these models have likewise increased in recent years (Bley, 2021; Felch & Asdecker, 2020; Pereira & Serrano, 2020; Pöppelbuß & Röglinger, 2011; Tarhan et al., 2016; van Looy, 2014). To substantiate these observations, the existing BPMM publications (1990–2019) were analyzed using two quality proxies: the impact factors of the publication outlets and the number of article citations. The analysis shows that previous studies are mainly published in less-recognized journals and are less frequently cited than other publications in the domain of BPM. A lack of methodological rigor, appropriate and comprehensible documentation, and relevance of the research for academia and practice, which are inherent parts of the most common scientific principles and peer-review processes, are identified as important reasons for this finding. This lack resulted in low transparency, replicability, and reproducibility, which eventually limit the models' usefulness and applicability to other researchers, consultants, and industry experts.

Despite the increasing awareness regarding the importance of quality criteria (van Looy et al., 2013; Wendler, 2012), domain-specific, viable suggestions have not yet been developed. The paper addresses this shortcoming, aiming to reduce the problem of quality assurance. Drawing on the DSR paradigm, quality criteria in four dimensions are highlighted: (1) design methodology, (2) model documentation, (3) model content scope, and (4) evolutionary ability (cf. Felch & Asdecker, 2020). It extends the general design principles presented by Pöppelbuß and Röglinger (2011) by considering a model's methodological rigor, content scope, and evolutionary ability. It thus provides a more holistic framework of quality criteria for BPMMs. Beyond that, the article exceeds the mere presentation of criteria by focusing mainly on the ex ante evaluations of the artifact (cf. Felch & Asdecker, 2020).

The designed artifact can provide important guidance to scholars, reviewers, and editors in their challenging and responsible tasks. On the one hand, the presented framework supports authors in developing more substantiated and replicable BPMMs, thereby increasing the chances of being published in more prestigious journals and conference proceedings. On the other hand, the framework provides a structured approach for reviewers and editors to assess a model's quality. In addition, this study contributes to practice. First, consultants and/or industry experts thinking about applying a BPMM can refer to the list of examined models. As a result of the model evaluation, decision-makers receive a comprehensive overview of the models' strengths and weaknesses, thus enabling an efficient decision on which model to resort to. Second, the use of the proposed criteria for the development of BPMMs will lead to the publication and dissemination of more transparent and solid models. Future BPMMs will better overcome the previous hurdle in terms of usefulness and applicability and thus be of more value to practitioners.

While the development of the artifact has been thoroughly conducted and the derived criteria can help authors, reviewers, and editors, the framework does not claim to be an exhaustive list of criteria. If, for example, new cause-effect relationships are empirically confirmed or new methods for model development, evaluation, or application arise, the relevant criteria must be adapted, requiring additional subsequent build-and-evaluate cycles. Consequently, the framework shall be interpreted as an orientation guide rather than a strict checklist, which needs to be continuously revised. Therefore, the authors of this paper call for this artifact to be updated, refined, and, if necessary, extended. If this call is heeded, the presented framework can catalyze the development of better, more applicable models. In other words, referring back to de Bruin and Rosemann (2007), it would limit the number of "power-point deep" models and promote, instead, rigorously developed and tested models that have the potential to be applied within a wide range of organizations.

Despite the predominant focus on ex ante evaluations, one part of the ex post evaluation was completed by analyzing the 25 previously published BPMMs ('EVAL3'). To complete it, the impact of the artifact needs to be reflected retrospectively. Up to this point, the framework has not been applied for model development and publication purposes. Consequently, no conclusions can yet be drawn about the usefulness of the derived artifact. To counteract this limitation, attention should be given to whether papers that refer to these criteria are released in higher-quality publication outlets and are cited more frequently. Thus, future literature reviews could analyze whether significant differences exist between articles that have relied on the criteria and those that have not. Further adjustments can be implemented through this final evaluation of the framework, such as adding suitable criteria. Another limitation is that there may be other reasons that prevent BPMMs from being published in higher-quality outlets. In that regard, it would be interesting to collect reviewer reports to analyze the reasons for acceptance or rejection. Finally, when discussing the quality of BPMM publications, it would be equally relevant to empirically investigate how many and which models are used in business practice and how successful their application is. Even with these limitations, we are convinced that this study contributes to the improvement of BPMMs so that in ten years, both the number and quality of publications will rise. In light of the ever-increasing competitive and economic pressures, such consistent further development is needed to better support the continuous improvement of business processes.

V.5 Appendix A. Overview of the Relevant Literature

The table provides an overview of all 34 articles classified as relevant.

No	Reference of relevant articles
1	Babic-Hodovic, V., Mehic, E., & Arslanagic, M. (2012). The Influence of Quality Practices on BH Companies' Business Performance. *International Journal of Management Cases, 14*(1), 305–316.
2	Becker, J., Knackstedt, R., & Pöppelbuß, J. (2009). Developing Maturity Models for IT Management – A Procedure Model and Its Application. *Business & Information Systems Engineering, 1*(3), 213–222.
3	Bronzo, M., Resende, P. T. V. de, de Oliveira, M. P. V., McCormack, K., de Sousa, P. R., & Ferreira, R. L. (2013). Improving Performance Aligning Business Analytics with Process Orientation. *International Journal of Information Management, 33*(2), 300–307.
4	de Bruin, T., Freeze, R., Kaulkarni, U., & Rosemann, M. (2005). Understanding the Main Phases of Developing a Maturity Assessment Model. In *Proceedings of the 16th Australasian Conference on Information Systems,* Sydney, Australia.
5	Diller, H., & Ivens, B. (2006). Process Oriented Marketing. *Marketing – Journal of Research and Management, 2*(1), 14–29.
6	Forsberg, T., Nilsson, L., & Antoni, M. (1999). Process Orientation: The Swedish Experience. *Total Quality Management, 10*(4–5), 540–547.
7	Fraser, P., Moultrie, J., & Gregory, M. (2002). The Use of Maturity Models/Grids as a Tool in Assessing Product Development Capability: A Review. In *Proceedings of the International Engineering Management Conference,* Cambridge, United Kingdom.
8	Gustafsson, A., Nilsson, L., & Johnson, M. D. (2003). The Role of Quality Practices in Service Organizations. *International Journal of Service Industry Management, 14*(2), 232–244.
9	Helgesson, Y. Y. L., Höst, M., & Weyns, K. (2012). A Review of Methods for Evaluation of Maturity Models for Process Improvement. *Journal of Software: Evolution and Process, 24*(4), 436–454.
10	Hellström, A., & Eriksson, H. (2013). Among Fumblers, Talkers, Mappers and Organisers: Four Applications of Process Orientation. *Total Quality Management & Business Excellence, 24*(6), 733–751.

No	Reference of relevant articles
11	Hernaus, T., Pejić Bach, M., & Bosilj-Vukšić, V. (2012). Influence of Strategic Approach to BPM on Financial and Non-financial Performance. *Baltic Journal of Management, 7*(4), 376–396.
12	Ittner, C. D., & Larcker, D. F. (1997). The Performance Effects of Process Management Techniques. *Management Science, 43*(4), 522–534.
13	Kohlbacher, M., & Gruenwald, S. (2011b). Process Ownership, Process Performance Measurement and Firm Performance. *International Journal of Productivity and Performance Management, 60*(7), 709–720.
14	Kohlbacher, M., & Gruenwald, S. (2011a). Process Orientation: Conceptualization and Measurement. *Business Process Management Journal, 17*(2), 267–283.
15	Kohlbacher, M., & Reijers, H. A. (2013). The Effects of Process-oriented Organizational Design on Firm Performance. *Business Process Management Journal, 19*(2), 245–262.
16	Kumar, V., Movahedi, B., Miri-Lavassani, K., & Kumar, U. (2010). Unleashing Process Orientation. *Business Process Management Journal, 16*(2), 315–332.
17	Lahrmann, G., Marx, F., Winter, R., & Wortmann, F. (2010). Business Intelligence Maturity Models: An Overview. In *Proceedings of the 7th Conference of the Italian Chapter of AIS,* Naples, Italy.
18	Leyer, M., Stumpf-Wollersheim, J., & Pisani, F. (2017). The Influence of Process-oriented Organisational Design on Operational Performance and Innovation: A Quantitative Analysis in the Financial Services Industry. *International Journal of Production Research, 55*(18), 5259–5270.
19	Maier, A. M., Moultrie, J., & Clarkson, P. J. (2012). Assessing Organizational Capabilities: Reviewing and Guiding the Development of Maturity Grids. *IEEE Transactions on Engineering Management, 59*(1), 138–159.
20	McCormack, K. (2001). Business Process Orientation: Do You Have It? *Quality Progress, 34*(1), 51–58.
21	McCormack, K., & Johnson, W. (2001). *Business Process Orientation: Gaining the E-Business Competitive Advantage.* St. Lucie press.

No	Reference of relevant articles
22	Mettler, T. (2009). *A Design Science Research Perspective on Maturity Models in Information Systems*. working paper. St. Gallen. Institute of Information Management, Universtiy of St. Gallen.
23	Mettler, T. (2010). Thinking in Terms of Design Decisions When Developing Maturity Models. *International Journal of Strategic Decision Sciences, 1*(4), 76–87.
24	Milanović Glavan, L., & Bosilj-Vukšić, V. (2017). Examining the Impact of Business Process Orientation on Organizational Performance: The Case of Croatia. *Croatian Operational Research Review, 8*(1), 137–165.
25	Movahedi, B., Miri-Lavassani, K., & Kumar, U. (2016). Operational Excellence through Business Process Orientation: An Intra- and Inter-organizational Analysis. *TQM Journal, 28*(3), 467–495.
26	Münstermann, B., Eckhardt, A., & Weitzel, T. (2010). The Performance Impact of Business Process Standardization: An Empirical Evaluation of the Recruitment Process. *Business Process Management Journal, 16*(1), 29–56.
27	Münstermann, B., Joachim, N., & Beimborn, D. (2009). An Empirical Evaluation of the Impact of Process Standardization on Process Performance and Flexibility. In *Proceedings of the 15th Americas Conference on Information Systems,* San Francisco, United States of America.
28	Nilsson, L., Johnson, M. D., & Gustafsson, A. (2001). The Impact of Quality Practices on Customer Satisfaction and Business Results: Product Versus Service Organizations. *Journal of Quality Management, 6*(1), 5–27.
29	Pöppelbuß, J., & Röglinger, M. (2011). What Makes a Useful Maturity Model? A Framework for General Design Principles for Maturity Models and Its Demonstration in Business Process Management. In *Proceedings of the 19th European Conference on Information Systems,* Helsinki, Finland.
30	Pradabwong, J., Braziotis, C., Tannock, J. D., & Pawar, K. S. (2017). Business Process Management and Supply Chain Collaboration: Effects on Performance and Competitiveness. *Supply Chain Management: An International Journal, 22*(2), 107–121.
31	Škrinjar, R., Bosilj-Vukšić, V., & Indihar-Štemberger, M. (2008). The Impact of Business Process Orientation on Financial and Non-financial Performance. *Business Process Management Journal, 14*(5), 738–754.

No	Reference of relevant articles
32	Sonnenberg, C., & vom Brocke, J. (2012a). Evaluation Patterns for Design Science Research Artefacts. In M. Helfert & B. Donnellan (Eds.), *Communications in Computer and Information Science, Practical Aspects of Design Science* (pp. 71–83). Springer.
33	van Steenbergen, M., Bos, R., Brinkkemper, S., van de Weerd, I., & Bekkers, W. (2010). The Design of Focus Area Maturity Models. In R. Winter, J. L. Zhao, & S. Aier (Eds.), *Lecture Notes in Computer Science: Vol. 6105, Global Perspectives on Design Science Research* (pp. 317–332). Springer.
34	Wendler, R. (2012). The Maturity of Maturity Model Research: A Systematic Mapping Study. *Information and Software Technology, 54*(12), 1317–1339.

V.6 Appendix B. Released BPMMs (1990–2014)

The table lists all 20 BPMMs that were classified as 'released' according to Tarhan et al. (2016) and published between 1990 and 2014. The numbers listed in the first column as well as the references of the articles were adopted from the article by Tarhan et al. (2016).

No	Reference of BPMM publications (1990–2014)
S3	Cronemyr, P., & Danielsson, M. (2013). Process Management 1-2-3 – A Maturity Model and Diagnostics Tool. *Total Quality Management & Business Excellence, 24*(7–8), 933–944.
S7	de Bruin, T., & Rosemann, M. (2007). Using the Delphi Technique to Identify BPM Capability Areas. In *Proceedings of the 18th Australasian Conference on Information Systems,* Toowoomba, Australia.
S12	Hammer, M. (2007). The Process Audit. *Harvard Business Review, April,* 1–14.
S13	Heinze, P., & Geers, D. (2009). Quality Management in Knowledge Intensive Business Processes – Development of a Maturity Model to Measure the Quality of Knowledge Intensive Business Processes in Small and Medium Enterprises. In *Proceedings of the 1st International Conference on Knowledge Management and Information Sharing,* Funchal, Portugal.
S14	Jadhav, M., & Sapre, G. (2009). The Business Process Maturity Model – A Tool to Assess Capability of Business Process. In *Proceedings of the 11th International Conference on Informatics and Semiotics in Organisations,* Beijing, China.
S16	Jochem, R., Geers, D., & Heinze, P. (2011). Maturity Measurement of Knowledge-intensive Business Processes. *TQM Journal, 23*(4), 377–387.
S17	Kangilaski, T., Polyantchikov, I., & Shevtshenko, E. (2013). Partner Network and its Process Management. In *Proceedings of the 10th International Conference on Informatics in Control, Automation and Robotics,* Reykjavík, Iceland.

No	Reference of BPMM publications (1990–2014)
S20	Lee, J., Lee, D., & Kang, S. (2007). An Overview of the Business Process Maturity Model (BPMM). In K. C.-C. Chang, W. Wang, L. Chen, C. A. Ellis, C.-H. Hsu, A. C. Tsoi, & H. Wang (Eds.), *Lecture Notes in Computer Science: Vol. 4537, Advances in Web and Network Technologies, and Information Management* (pp. 384–395). Springer.
S22	Moradi-Moghadam, M., Safari, H., & Maleki, M. (2013). A Novel Model for Business Process Maturity Assessment through Combining Maturity Models with EFQM and ISO 9004:2009. *International Journal of Business Process Integration and Management, 6*(2), 167–184.
S25	Paunescu, C. (2009). Business Maturity Assessment Model: A Practical Approach for Identifying Opportunities for Sustainability Improvement. In *Proceedings of the Annals of DAAAM and Proceedings of the 20th International DAAAM Symposium,* Vienna, Austria.
S31	Rohloff, M. (2009a). An Approach to Assess the Implementation of Business Process Management in Enterprises. In *Proceedings of the 17th European Conference on Information Systems,* Verona, Italy.
S32	Rohloff, M. (2010). Advances in Business Process Management Implementation based on a Maturity Assessment and Best Practice Exchange. *Information Systems and E-Business Management, 9*(3), 383–403.
S33	Rohloff, M. (2009b). Case Study and Maturity Model for Business Process Management Implementation. In U. Dayal, J. Eder, J. Koehler, & H. A. Reijers (Eds.), *Lecture Notes in Computer Science: Vol. 5701, Business Process Management* (pp. 128–142). Springer.
S34	Rohloff, M. (2009c). Process Management Maturity Assessment. In *Proceedings of the 15th Americas Conference on Information Systems,* San Francisco, United States of America.
S36	Rosemann, M., de Bruin, T., & Hueffner, T. (2004). A Model for Business Process Management Maturity. In *Proceedings of the 10th Americas Conference on Information Systems,* New York, United States of America.
S37	Rosemann, M., & de Bruin, T. (2005). Towards a Business Process Management Maturity Model. In *Proceedings of the 13th European Conference on Information Systems,* Regensburg, Germany.
S38	Saco, R. M. (2008). Maturity Models: Inject New Life. *Industrial Management, 50*(4), 11–15.

No	Reference of BPMM publications (1990–2014)
S40	Škrinjar, R., Dimovski, V., Škerlavaj, M., & Indihar-Štemberger, M. (2006). Process Maturity and Organizational Structure as a Framework for Performance Improvements. In A. G. Nilsson, R. Gustas, W. Wojtkowski, S. Wrycza, & J. Zupančič (Eds.), *Advances in Information Systems Development* (pp. 95–106). Springer.
S59	Willaert, P., van den Bergh, J., Willems, J., & Deschoolmeester, D. (2007). The Process-Oriented Organisation: A Holistic View Developing a Framework for Business Process Orientation Maturity. In G. Alonso, P. Dadam, & M. Rosemann (Eds.), *Lecture Notes in Computer Science, Business Process Management* (pp. 1–15). Springer.
S61	Zwicker, J., Fettke, P., & Loos, P. (2010). Business Process Maturity in Public Administrations. In J. vom Brocke & M. Rosemann (Eds.), *Handbook on Business Process Management 2: Strategic Alignment, Governance, People and Culture* (pp. 485–512). Springer.

V.7 Appendix C. Released BPMMs (2015–2019)

The table contains all five BPMMs that were classified as 'released' according to Felch and Asdecker (2020) and published between 2015 and 2019. The numbers listed in the first column as well as the references of the articles were adopted from the article by Felch and Asdecker (2020).

No	Reference of BPMM publication (2015–2019)
A2	Andriani, M., Samadhi, T. A., Siswanto, J., & Suryadi, K. (2018). Aligning Business Process Maturity Level with SMEs Growth in Indonesian Fashion Industry. *International Journal of Organizational Analysis, 26*(4), 709–727.
A4	Chaghooshi, A. J., Moradi-Moghadam, M., & Etezadi, S. (2016). Ranking Business Processes Maturity by Modified Rembrandt Technique with Considering CMMI Dimensions. *Iranian Journal of Management Studies, 9*(3), 559–578.
A11	Froger, M., Bénaben, F., Truptil, S., & Boissel-Dallier, N. (2019). A Non-linear Business Process Management Maturity Framework to Apprehend Future Challenges. *International Journal of Information Management, 49*, 290–300.
A34	Sliż, P. (2018). Concept of the Organization Process Maturity Assessment. *Journal of Economics and Management, 33*(3), 80–95.
A50	Berger, R., Wellbrock, W., Aksoy, O., & Mulzer, D. (2018). Process Orientation: An Approach to Optimize Cross-company Supply Chains - Insights from a Descriptive Study. In *Proceedings of the 30th Annual NOFOMA Conference,* Kolding, Denmark.

V.8 Appendix D. Overview of the Analyzed BPMMs (1990–2019)

The following tables show the detailed results of the analyzed BPMMs regarding the four derived dimensions: (1) design methodology, (2) model documentation, (3) model content scope, and (4) evolutionary ability. The BPMMs associated with the numbers can be gathered from the Appendices B and C.

(1) Design methodology

Unit of analysis	Appropriate approaches to ensure BPMM design methodology quality	S3	S7	S12	S13	S14	S16	S17	S20	S22	S25	S32
Procedure model	Procedure model											
	Others											
Development method	Literature review	x	x		x		x		x	x	x	x
	Case study		x									
	Delphi study		x									
	Focus group											
	Others	x			x		x					x
Evaluation method	Demonstration with prototype			x			x					
	Experiment with prototype or system			x								x
	Benchmarking											
	Survey								x			
	Expert interview											
	Focus group		x				x					
	Others		x	x					x			
Application method	Case study											x
	Field experiment											
	Survey	x										
	Expert interview											x
	Focus group											

Unit of analysis	Appropriate approaches to ensure BPMM design methodology quality	S36	S37	S38	S40	S59	S61	A2	A4	A11	A34	A50
Procedure model	Procedure model										x	x
	Others						x					
Development method	Literature review	x	x		x	x	x	x		x	x	x
	Case study					x						
	Delphi study		x									
	Focus group											
	Others		x			x	x					
Evaluation method	Demonstration with prototype											
	Experiment with prototype or system											
	Benchmarking											
	Survey		x									
	Expert interview						x	x				
	Focus group											
	Others		x				x	x				
Application method	Case study	x		x			x		x	x		
	Field experiment											
	Survey											x
	Expert interview											
	Focus group											

(2) Model documentation

Unit of analysis	Necessary content to ensure BPMM documentation quality	S3	S7	S12	S13	S14	S16	S17	S20	S22	S25	S32
Intended model purpose	Descriptive	x		x	x	x	x	x	x	x	x	x
	Prescriptive	x			x	x	x		x	x	x	x
	Comparative				x		x					x
Basic components of all models	Number of levels	x		x		x	x	x	x	x		x
	Descriptor for each level	x		x		x	x	x	x	x		x
	Generic description of each level	x		x		x	x	x	x	x		x
	Number of dimensions	x	x	x		x	x	x	x	x	x	x
	Number of elements for each process area		x	x		x	x		x	x		x
	Description of each activity			x						x		x
Components of descriptive maturity models	Intersubjectively verifiable criteria	x		x			x	x	x	x		x
	Assessment methodology	x		x		x	x			x		x
Components of prescriptive maturity models	Improvement measures											
	Decision calculus to select measures											
	Decision methodology											

Unit of analysis	Necessary content to ensure BPMM documentation quality	S36	S37	S38	S40	S59	S61	A2	A4	A11	A34	A50
Intended model purpose	Descriptive	x	x	x			x	x	x	x	x	x
	Prescriptive	x	x	x			x	x			x	
	Comparative	x	x								x	
Basic components of all models	Number of levels	x	x	x	x		x	x	x		x	x
	Descriptor for each level	x	x	x	x		x	x	x		x	x
	Generic description of each level			x	x		x	x	x		x	x
	Number of dimensions	x	x	x	x	x	x	x	x	x	x	x
	Number of elements for each process area	x		x			x	x	x	x	x	x
	Description of each activity						x					
Components of descriptive maturity models	Intersubjectively verifiable criteria						x	x			x	x
	Assessment methodology	x		x					x		x	
Components of prescriptive maturity models	Improvement measures											
	Decision calculus to select measures											
	Decision methodology											

(3) Model content scope

Unit of analysis	Relevant components to ensure BPMM content quality	S3	S7	S12	S13	S14	S16	S17	S20	S22	S25	S32
Organization	Organizational structure	x		x					x			
	Strategic alignment		x	x		x	x	x		x	x	x
	Culture		x	x		x						
Supply chain integration	Supplier orientation			x				x	x	x		
	Customer orientation		x	x			x	x	x	x		
Process	Process focus/ orientation		x			x		x			x	
	Process owner	x	x	x		x		x		x	x	x
	Definition and documentation	x	x	x		x		x	x	x		x
	Design of processes	x	x	x				x	x	x	x	
	Measurement of processes	x	x	x		x		x	x	x	x	x
	Improvement of processes	x	x	x					x	x	x	x
IT	Support by IT-tools		x	x		x	x	x		x		x
Employees	Design of jobs and workplace			x				x		x		
	Employee development		x	x						x		x
	Employee involvement and motivation	x		x				x				
	Employee information exchange		x			x						x

Unit of analysis	Relevant components to ensure BPMM content quality	S36	S37	S38	S40	S59	S61	A2	A4	A11	A34	A50
Organization	Organizational structure		x	x		x				x	x	x
	Strategic alignment		x				x	x	x	x	x	x
	Culture	x	x			x			x			x
Supply chain integration	Supplier orientation			x		x			x			x
	Customer orientation			x		x		x	x			x
Process	Process focus/ orientation					x			x			
	Process owner	x		x		x	x		x			x
	Definition and documentation					x	x	x	x	x	x	x
	Design of processes			x			x	x	x	x		x
	Measurement of processes	x		x		x	x	x	x	x		x
	Improvement of processes	x		x		x	x		x		x	x
IT	Support by IT-tools	x	x			x	x	x	x	x		x
Employees	Design of jobs and workplace									x		
	Employee development					x	x		x	x	x	x
	Employee involvement and motivation					x	x				x	x
	Employee information exchange						x		x			x

(4) Evolutionary ability

Unit of analysis	**Evolutionary elements to ensure BPMM long-term quality**	**S3**	**S7**	**S12**	**S13**	**S14**	**S16**	**S17**	**S20**	**S22**	**S25**	**S32**
Model components	Form						x					
	Functioning											
Parameters of change	Frequency of change											
	Initiator of change											
Others									x			

Unit of analysis	**Evolutionary elements to ensure BPMM long-term quality**	**S36**	**S37**	**S38**	**S40**	**S59**	**S61**	**A2**	**A4**	**A11**	**A34**	**A50**
Model components	Form		x							x		
	Functioning											
Parameters of change	Frequency of change									x		
	Initiator of change		x									
Others							x					

V.9 References

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Article VI. Do Procedure Models Actually Guide Maturity Model Design? A Citation Analysis

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Abstract. More than a decade ago, guidelines for the development of maturity models were proposed in the form of procedure models. In theory, such procedure models provide scholars with guidance, but does the scientific community actually use them according to their intended purpose. This paper conducts a citation analysis and identifies an impressive number of citations. However, it is noteworthy that the publications are mainly cited for other reasons, such as the components or the general purposes of maturity models. The analysis also provides indications that many maturity models are developed without using a procedure model. Despite the fact that methodological rigor is considered a crucial criterion for publishing articles, maturity model designers might have concerns about using domain-specific procedure models. Future studies should address the reasons for this reluctance.

Keywords. Maturity Model · Procedure Model · Digitalization · Industry 4.0 · Citation Analysis

VI.1 Introduction

Ongoing digitalization and the related Industry 4.0 represent an area characterized by unpredictable dynamics that continuously change the status quo (Verhoef et al., 2021). This has a considerable impact on business processes, leading to a transformation in organizations (Bley, 2021; de Carolis, Macchi, Negri, & Terzi, 2017; Leyh et al., 2017; Schmidt et al., 2017). Maturity models can contribute to this organizational transformation and capability renewal by initiating and accompanying change processes (Colli et al., 2019; Mettler, 2010; Solli-Sæther & Gottschalk, 2010; Trautmann, 2021). They can be useful in determining the organization's current state, providing improvement measures, and conducting cross-organizational comparisons (Felch et al., 2019; Pöppelbuß & Röglinger, 2011). For years, maturity models, including those relating to digitalization and Industry 4.0, have received great attention in both academia and business practice (Bley, 2021; Gökşen & Gökşen, 2021; Pöppelbuß et al., 2011; Pöppelbuß & Röglinger, 2011; Wendler, 2012). Despite their importance, several researchers have criticized the arbitrary development process of maturity models focusing on digitalization and Industry 4.0 (e.g., Caiado et al., 2021; Nottbrock, 2021). This issue is by no means new; almost two decades ago, maturity models, in general, were already criticized for their quality, particularly the development process. Insufficient documentation (J. Becker et al., 2009; Pöppelbuß & Röglinger, 2011), a lack of scientific rigor (Maier et al., 2012; Rosemann & de Bruin, 2005; Solli-Sæther & Gottschalk, 2010), and "a certain arbitrariness" (J. Becker et al., 2009, p. 214) were criticisms raised at that time.

Considering that the literature back then provided insufficient guidance on how to design maturity models, de Bruin et al. (2005) proposed an initial procedure model in 2005. Subsequently, other procedure models, such as those by J. Becker et al. (2009), Maier et al. (2012), Mettler (2010), Solli-Sæther and Gottschalk (2010), or van Steenbergen et al. (2010), followed, suggesting similar steps necessary to develop a maturity model. The guidelines aim to support a purposeful design and ensure scientific rigor to publish more transparent and substantiated maturity models.

They can be applied regardless of the research area addressed by the maturity model. The target audience for such models, apart from consultants and industry experts, is mainly researchers, as the use of adequate methods is required by common scientific principles and in peer-review processes (Bornmann et al., 2008). Despite these domain-specific procedure models, other generic research guiding methodologies exist. More than a decade ago, de Bruin et al. (2005) and J. Becker et al. (2009) pointed out that only future studies can measure the impact of procedure models on the maturity model community and whether the guidelines prove to be effective and useful. In addition to the renewed criticism regarding the development process of models addressing digitalization and Industry 4.0, R. Pereira and Serrano (2020, p. 162) recently stated that "[...] authors still do not adopt these methods". However, apart from this anecdotal evidence, no systematic analysis of procedure models' impact has been conducted. The paper at hand responds to this call for an evaluation. Thus, the research question is:

Are the procedure model publications actually used for their intended purpose, i.e., as guidance for maturity model design?

This paper contributes to the methodological aspects of maturity model research (cf. Pöppelbuß et al., 2011). The findings of the article create awareness of the fact that, thus far, these guidelines have rarely been used for developing maturity models. Several research streams arise from the obtained results, including (1) evaluating the suitability and (2) gathering data on the user-related requirements of procedure models and other research methodologies for maturity model development.

The remainder of the article is structured as follows: The next section provides a rationale for the relevance of research methodologies, particularly procedure models, and describes how to measure an article's impact on the scientific community. Subsequently, data collection and processing are described, followed by the presentation of the results. The paper concludes with its contribution to the field.

VI.2 Motivational Background

It is crucial to discuss whether research methodologies, such as procedure models, are needed in the first place (Section VI.2.1) before outlining how the impact of an article can be measured (Section VI.2.2).

VI.2.1 Are Procedure Models Really Needed?

Choosing the appropriate research methodology is one of the most important decisions for scholars, as it affects the quality of their research and the chance of publication in high-quality outlets (Straub, 2009). Research methodology is understood to be a logically structured process consisting of a sequence of different steps that enable designing and conducting research (Crotty, 1998). Procedure models depict such a systematic process for the development of maturity models (R. Pereira & Serrano, 2020). The application and documentation of the research guiding methodology help scholars conduct more rigorous research that can be perceived as such by reviewers and editors (Rosemann & Vessey, 2008). In addition, the application and subsequent disclosure of the methodology increase the transparency of the research process, which, in turn, is a strong indicator of the reproducibility and replicability of the results (Aguinis et al., 2018; Campbell et al., 2014). Therefore, the use of appropriate methodologies and methods is included in the most common scientific principles (Canadian Institutes of Health Research, Natural Sciences and Engineering Research, Social Sciences and Humanities Research Council of Canada, 2016; Deutsche Forschungsgemeinschaft, 2019; National Academy of Sciences, 2009; UK Research Integrity Office, 2009) that are decisive criteria of peer-review processes. Consequently, the research methodology can be considered a mechanism for quality assurance in research.

When selecting the underlying research methodology, special attention should be given to its appropriateness, i.e., its suitability for the intended purpose (D. H. Walker, 1997). Since some research domains have their idiosyncrasies, it can be useful to develop domain-specific research methodologies (Davies et al., 1999; Denyer & Tranfield, 2009; Durach et al., 2017). The domain of maturity models is characterized by such idiosyncrasy as the fact that they prescribe a linear, predefined sequence of steps to reach an ideal end state (J. Becker et al., 2009; Fraser et al., 2002; Pöppelbuß & Röglinger, 2011). Maturity models constitute practical solutions for organizations. They enable companies to continuously improve their performance and increase their ability to remain competitive. Furthermore, maturity models contain dynamic elements to be able to adapt to new circumstances, e.g., new scientific findings or technological changes, and, thus, remain their model relevance (J. Becker et al., 2009; Maier et al., 2012; Mettler, 2010). These idiosyncrasies justify the engagement of various researchers, such as de Bruin et al. (2005) and J. Becker et al. (2009), with epistemological assumptions and the development of procedure models as a domain-specific methodology intended to support designers in creating solid and substantiated maturity models.

In general, research aims to propose a solution for a particular concern or problem (Creswell & Creswell, 2018; Kothari, 2004; R. Weber, 2003). Subsequent to artifact development, the focus is on evaluating whether the concern or problem was actually solved or at least improved by the artifact (Rosemann & Vessey, 2008). This ex post evaluation involves comparing the preset objective with the actual observed results of using the artifact. The alignment between the problem and artifact can, in turn, provide an impetus for subsequent iterations to improve the artifact. Although procedure models have been available for years and a retrospective consideration of the articles' impact has been called for (cf. J. Becker et al., 2009; de Bruin et al., 2005), such an analysis is still lacking. The paper at hand responds to this call for an evaluation. The following section addresses how an article's impact can be measured.

VI.2.2 Reflection on Citation Analyses

Citation analyses are frequently performed to measure a publication's impact on the scientific community (Bornmann, 2011; Lowry et al., 2007; Recker & Mendling, 2016). They are based on the number of times an article has been cited by other works (Lowry et al., 2007; Meho, 2007). In the long term, articles perceived as useful by the community are used and cited more often, while articles considered less useful are referenced more seldom (Lowry et al., 2007). Consequently, "[...] papers with more citations are considered significantly more influential than articles with fewer citations" (Nyam et al., 2020, p. 6).

Often, each citation of an article is considered to be of equal value (Mettler & Ballester, 2021; Rüdiger et al., 2021). In recent years, doubts about this view and the mere consideration of an article's citation count have been raised (e.g., Mettler & Ballester, 2021; Rüdiger et al., 2021). Instead, it is suggested that the citation type be considered in more detail. Various approaches have already been proposed in the literature (cf. Anderson & Lemken, 2020; Bornmann et al., 2020; Rüdiger et al., 2021; G. Zhang et al., 2013). As an example, the value of the citation can be determined by assessing the location, frequency, or even style of the citation in an article (Rüdiger et al., 2021; G. Zhang et al., 2013). Additionally, a citation context analysis can be performed (Anderson & Lemken, 2020; Bornmann et al., 2020), which involves extracting the content to which the citing author(s) refer. Thus, it can be concluded whether, for example, the referenced content refers to the main research focus of the cited article. Such detailed classification can improve conventional citation analysis (Rüdiger et al., 2021) and allow more precise conclusions to be drawn regarding the phenomenon of interest, i.e., an article's impact on the community.

To conduct the retrospective analysis of procedure model articles and understand how such models have shaped the academic discourse, the study at hand relies on a citation context analysis. The findings are presented in the following paragraph.

VI.3 Citation Context Analysis of Procedure Model Publications

Summarizing the current research streams in maturity model research, Patas et al. (2013) mentioned six procedure models released by the following authors: (1) J. Becker et al. (2009) (B09), (2) de Bruin et al. (2005) (D05), (3) Maier et al. (2012) (M12), (4) Mettler (2010) (M10), (5) Solli-Sæther and Gottschalk (2010) (S10), and (6) van Steenbergen et al. (2010) (V10). Using citation context analysis, the impact of these six articles on the maturity model community is determined. The process and results of the analysis are presented in the following sections.

VI.3.1 Citation Context Analysis: Method

Scopus or Web of Science databases are recommended for retrieving the citation data (Nunhes & Oliveira, 2020; Waltman, 2016). Since two of the six procedure model articles (D05, M10) are not listed in Web of Science and just one paper (M10) is not included in Scopus, the latter was used. A total of 708 citations (as of November 2021) were identified that reference one of the five remaining publications (see Table VI.1).

	B09	**D05**	**M12**	**S10**	**V10**	**Σ**
Initially retrieved citations	77	378	135	50	68	708
Exclusion of						
Non-English citations	16	15	2	1	2	36
Non-academic citations	0	0	1	0	0	1
Duplicates within database	1	1	1	0	1	4
Self-citations	1	0	5	1	6	13
Non-accessible citations	3	6	3	1	0	13
Missing in-text citations	0	2	1	0	2	5
Finally selected citations	56	354	122	47	57	636

Table VI.1. Citations retrieved and selection process

Next, the search results were screened using six criteria. For example, citations not published in English were excluded from further consideration. In this way, the number of citations was reduced to 636, distributed among 517 individual articles from various areas, e.g., process and innovation management, service engineering, and e-collaboration (see Appendix B). The majority of articles (421) cite one procedure model publication, while only 20 articles cite between three and five publications (see Table VI.2). The consideration of the citation count shows that D05 (354 citations) and M12 (122) have been cited most frequently, followed by V10 (57), B09 (56), and S10 (47) (see Table VI.1). To account for different publication dates and allow better comparability, the average citations per year are calculated (see Appendix A). Again, D05 (19.7 citations per year) and M12 (11.1) show the highest values. More than half of all citations, namely, 391, were gathered in the last five years (2017–2021). In 2020, in particular, citations increased considerably for all five articles (see Appendix A).

Number of cited procedure models	Number of articles	Cumulative percentage
5	0	0.0 %
4	3	0.6 %
3	17	3.9 %
2	76	18.6 %
1	421	100.0 %

Table VI.2. Number of cited procedure model publications within the articles

In the following, the paper focuses on the context of those citations. The aim is to determine whether the five articles are cited for their main research focus, i.e., the procedure model for model development. First, the in-text citations were highlighted in each of the 517 articles. Special attention was given to the different citation styles, e.g., (last name of the author(s), year of publication) or [1], but also to spelling errors within the citations to include all in-text citations accordingly. A total of 1,805 in-text citations were identified. On average, each of the 517 articles has

3.5 in-text citations. Second, MAXQDA 2022 was used to analyze the in-text citations for their respective purpose to classify them into one of the following categories: citations placed for (C1) applying the procedure model for maturity model development, (C2) discussing/comparing the procedure model(s), or (C3) serving another purpose. C1 citations refer to a partial or full application of at least one procedure model for model design, whereas C2 citations refer to at least two models discussing their differences. C3 citations address a textual aspect beyond the procedure models, e.g., the relevance or definition of maturity models. Due to the interpretative nature of natural language, the classification of the in-text citations was not automatically performed based on certain preset rules. Instead, they were classified manually. For accurate classification, the assumption was followed: "[...] words likely to describe the use of the cited publication occur close to the citation, whereas words further away are less likely to describe the cited paper" (Rüdiger et al., 2021, p. 9785). Accordingly, in addition to the sentence in which the citation is located, the preceding and following sentences were considered (cf. Bornmann et al., 2020). When this did not lead to an unambiguous classification, the entire paragraph containing the citation was examined. Articles with more than one in-text citation were assigned to more than one category. For example, the article by Wißotzki and Koç (2013, p. 297) refers to the criticism stated by B09 (classified in C3): "The models have a poor theoretical basis and they are not well-documented". Furthermore, they apply B09's procedure model for their maturity model design (classified in C1): "The maturity model development process (MMDP) proposed in this paper is based on the maturity model development procedure of Becker et al. [29] and is illustrated in Figure 3" (Wißotzki & Koç, 2013, p. 300).

VI.3.2 Citation Context Analysis: Results

The classification results show that a minority of in-text citations, namely, 173 (9.6 %), are assigned to C1 and thus to the main research focus of the publications (see Table VI.3 and Appendix B). Only 109 articles apply at least one of the five procedure models to actually develop a maturity model. An illustrative example of classifying into C1 is "Steenbergen et al. (2010) provides guidelines for the development of maturity models, and recommends comparison with existing models, followed by an iterative procedure to define focus areas and capabilities, starting from literature, including expert input and possibly surveys in order to obtain a generally agreed model. This procedure is followed in the design of the PCMM" (Hermans et al., 2014, p. 1307). C2 accounts for 446 in-text citations (24.7 %), distributed among 181 articles. These publications include, for example, Wißotzki and Koç (2013) and García-Mireles et al. (2012), who compare the different procedure models, including B09 and D05, in tabular form. However, a total of 1,186 in-text citations (65.7 %) contained in 446 articles are assigned to C3 ('other purposes'). Thus, the citing articles do not reference the procedure model publications predominantly for their main research focus. The most frequent citation purposes that relate to C3 are the components of maturity models (234 in-text citations, e.g., Lahrmann & Marx, 2010), the general purposes of maturity models (185, e.g., Adrodegari & Saccani, 2020; de Carolis, Macchi, Kulvatunyou, et al., 2017), and criticism regarding maturity models (100, e.g., Frick et al., 2013; Proença & Borbinha, 2016). Citations tracked shortly after releasing the procedure model publications are classified into either C2 or C3 (see Appendix C). Presumably, due to the time-intensive model development process, the first applications of procedure models (B09 and D05) were recorded in 2011. In recent years, a marginal decline in citations can be observed for C1. Meanwhile, C2 remained at a constant level, while citations in C3 increased considerably.

	B09	**D05**	**M12**	**S10**	**V10**	**Σ**
C1	32	101	23	8	9	173
C2	68	265	58	36	19	446
C3	81	655	267	84	99	1,186
Σ	*181*	*1,021*	*348*	*128*	*127*	*1,805*

Table VI.3. Number of in-text citations by category

A more detailed analysis of C1 shows that D05's procedure model was by far the most frequently used among the citing articles (75). This is followed in descending order by B09 (18), M12 (10), V10 (7), and S10 (6) (see Appendix D). A total of 103 of the 109 articles applied one procedure model for model design. Five articles (Antonsen & Madsen, 2021; Siedler et al., 2021; Smits & van Hillegersberg, 2014, 2015; Thordsen & Bick, 2020) use a combination of two procedure models, while one paper (D. Jin et al., 2014) combines three models.

Additionally, to assess the influence of the procedure model publications, the number of maturity models developed with a procedure model (109) needs to be compared with the number of models released to date. The results are positioned in the context of digitalization and Industry 4.0 as an area characterized by unpredictable dynamics that continuously change what can be considered the status quo (Verhoef et al., 2021). To successfully cope with this organizational transformation, maturity models focusing on digitalization and Industry 4.0 have emerged as useful tools (Bley et al., 2020). The comprehensive review by Caiado et al. (2021) identified a total of 24 models, of which only 5 (20.8 %) (Asdecker & Felch, 2018; Rübel et al., 2018; Schumacher et al., 2016; Scremin et al., 2018; C. Weber et al., 2017) rely on a procedure model for model design (see Table VI.4 and Appendix E).

	Maturity model by
Procedure model	Asdecker and Felch (2018), Rübel et al. (2018), Schumacher et al. (2016), Scremin et al. (2018), C. Weber et al. (2017)
Other research methodology	–
No explicit reference	Akdil et al. (2018), Bibby and Dehe (2018), Canetta et al. (2018), Castor et al. (2016), de Carolis, Macchi, Kulvatunyou, et al. (2017), Ganzarain and Errasti (2016), E. Gökalp et al. (2017), Jung et al. (2016), Katsma et al. (2011), Leineweber et al. (2018), Leyh et al. (2016), Lichtblau et al. (2015), Oleśków-Szłapka and Stachowiak (2019), Pessl (2017), PricewaterhouseCoopers (2018), Qin et al. (2016), Rockwell Automation (2014), Wang et al. (2016), Zheng and Ming (2017)

Table VI.4. Overview of applied research methodologies

The remaining 19 articles do not report using other generic frameworks, procedure models, or research methodologies that aid in developing artifacts, such as design science research, to create their maturity model. Instead, these papers focus on the various methods used to develop, evaluate or validate the model (see, for example, Bibby & Dehe, 2018; Oleśków-Szłapka & Stachowiak, 2019; Zheng & Ming, 2017). Only a few articles refer to particular principles, such as a comparison of existing maturity models (e.g., Akdil et al., 2018; Bibby & Dehe, 2018; Canetta et al., 2018; E. Gökalp et al., 2017), on which the procedure models are also built.

However, a generic research methodology for model development is not made explicit. As already highlighted in section VI.2.1, disclosing the research methodology leads to a more rigorous and transparent research process (Aguinis et al., 2018; Campbell et al., 2014; Rosemann & Vessey, 2008). However, a reason for hiding may be that the chances of publication in higher quality outlets are simultaneously affected, as already noted by Alexander (1964, p. 8): “The use of logical structures to represent design problems [...] brings with it the loss of innocence. A logical picture is easier to criticize than a vague picture since the assumptions it is based on are brought out into the open. Its increased precision gives us the chance to sharpen our conception of what the design process involves.”

The finding on the application frequency of procedure models is further supported by Felch and Asdecker (2022), who concluded that out of 25 articles releasing a business process maturity model, only two refer to such procedure models. Various researchers, such as Pöppelbuß et al. (2011), Lasrado et al. (2016) and R. Pereira and Serrano (2020), emphasize that the development of new models is often based on existing models instead of domain-specific methodologies. Altogether, the results indicate that the number of maturity models developed with a procedure model is considerably lower than the number of maturity models released thus far. Therefore, the impact of the procedure model publications on the scientific community can be considered moderate.

VI.4 So What? Contributing to a Research Agenda

This research used citation context analysis to evaluate the impact of procedure models on the scientific community. It turns out that such models were often not cited for their intended purpose. To gain an understanding of how widespread the use in the model development actually is, digitalization and Industry 4.0 maturity models were analyzed. Two things became apparent: (1) Very few of these models referred to a scientifically recognized development methodology; and (2) in the rare case in which a methodology is applied, it is a procedure model. This rather surprising finding raises several new questions that form the basis of a research agenda. Due to the limited space, only the three most intriguing ones are addressed in the following.

First, the results of the study are considered in the context of digitalization and Industry 4.0. It would be interesting to know whether these findings are a peculiarity of this area or can be generalized. In addition, it raises the question of whether different generic frameworks or research methodologies are used in the other areas of which future digitalization or Industry 4.0 models could benefit. Thus, two important research leading questions are as follows:

- Which methodologies for maturity model development are used in other areas?
- Which parallels can be drawn with the results achieved thus far?

Second, despite the idiosyncrasies of maturity models and the suggestion of domain-specific research methodologies, the study's insights reignite the discussion about the necessity of procedure models. It should be questioned whether domain-specific research methodologies are necessary in this case. Furthermore, the question arises whether other research methodologies have the potential to better serve the intended purpose, namely, the development of solid and rigorous digitalization and Industry 4.0 maturity models. This leads to the following research guiding questions:

- Are the current domain-specific approaches even necessary?
- Are there (better) alternatives to procedure models?

Third, the perspective of maturity model designers has been neglected thus far, despite being crucial for the dissemination and success of such guidelines. It would be interesting to know how the procedure models are perceived by the digitalization and Industry 4.0 community. To derive possible adjustments for the procedure models or other guiding research methodologies, or even to establish a new approach, it is necessary to shed light on the phases of an application (model selection, deployment preparation, model application). Three essential research guiding questions are, therefore:

- Are procedure models perceived at all by the developers of digitalization and Industry 4.0 models? And if so, how?
- Which criteria are considered to decide for or against applying a procedure model?
- Which problems are encountered during the preparation and application of procedure models?

The proposed research streams do not represent an exhaustive list. Rather, they highlight relevant aspects to unfold the potential of the dynamic, ever-growing area of digitalization and Industry 4.0 models.

VI.5 Conclusion

The paper at hand evaluates the impact of procedure model articles published years ago and thus takes a critical view of the designed artifacts. The derived research agenda formulates specific research guiding questions to further address the initial problem of the arbitrary development process of digitalization and Industry 4.0 maturity models, thus advancing the area accordingly. The proposed research streams guide future efforts of researchers to specific priorities arising from identified opportunities and challenges. What can fellow researchers take away from these findings? First, it may be worthwhile to apply a procedure model for model design, regardless of whether it is the best methodology. The comparison with the values of Felch and Asdecker (2020) shows that the average impact factors of articles that refer to a procedure model (C1, Reuters Index: 4.3, H Index: 65.1, SJR: 0.9) are higher, implying that these are published in higher-quality outlets. Second, it can be useful to develop domain- and area-specific procedure models that address the peculiarities of individual areas, including digitization and Industry 4.0. Similar approaches can be found in systematic literature reviews that are both generic (e.g., vom Brocke et al., 2009) and area-specific (e.g., for SCM by Durach et al., 2017). Third, this paper contributes to the discussion on the mere consideration of an article's citation count. The results reinforce the extension of conventional citation analysis by taking a closer look at the citation type, especially the citation context. Despite the promising potential of citation context analysis, this work is the first to apply the approach to the maturity model domain. Other scholars can adopt this approach to conduct in-depth evaluations of the intended use of other research methodologies, such as those applied in action or design science research.

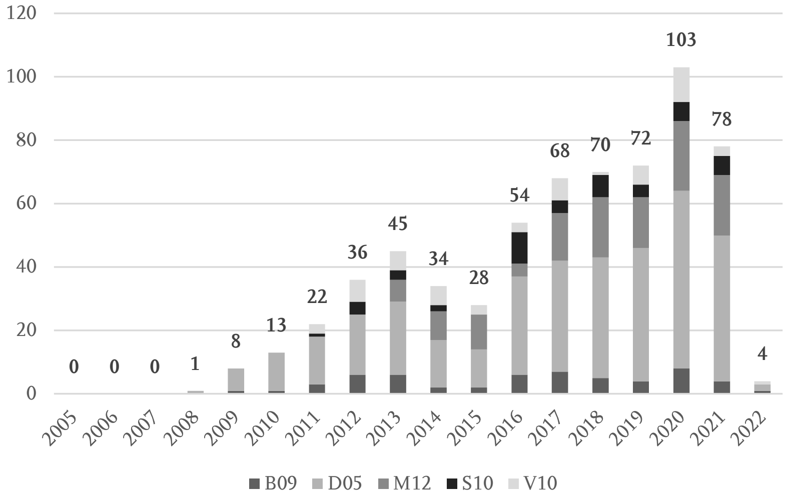
A limitation of the paper is that just one database, namely, Scopus, was used to retrieve the citation data. Using multiple databases, e.g., combining the citation data of Scopus and Web of Science, would, at first glance, result in a more comprehensive overview. However, since not all five remaining articles are listed in both databases (see section VI.3.1), this approach would lead to a biased presentation of the results and, thus, does not constitute a more rigorous approach. For this reason, the paper at hand focused on the most comprehensive database, which contains a broad spectrum of journal and conference articles from almost all disciplines. In addition, other procedure models (e.g., Mettler, 2010) exist, but their impact on the community was not considered in this case. However, the approach described in the article can be adopted for other guidelines. Beyond that, it should be pointed out that citation (context) analysis is only one indicator to measure an article's impact. Future studies should also consider other indicators to further validate the article's results. Finally, it should be noted that due to a lack of standardized terminology, a potential selection bias might occur regarding the procedure models. To address this issue, the 24 maturity models were analyzed regarding any type of development methodology. In the absence of any other approach, the sample can be considered appropriate. Despite these limitations, the paper contributes to raising awareness about the limited application of procedure models, originally intended to eliminate criticism regarding the model development process and to increase their quality in the long term.

VI.6 Appendix A. Citations per Year

The table contains the citation counts of the five procedure model publications per year and the average citations per year. Thus, the table serves as base for the figure below.

	B09	**D05**	**M12**	**S10**	**V10**
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	0	0	0
2008	0	1	0	0	0
2009	1	7	0	0	0
2010	1	12	0	0	0
2011	3	15	0	1	3
2012	6	19	0	4	7
2013	6	23	7	3	6
2014	2	15	9	2	6
2015	2	12	11	0	3
2016	6	31	4	10	3
2017	7	35	15	4	7
2018	5	38	19	7	1
2019	4	42	16	4	6
2020	8	56	22	6	11
2021	4	46	19	6	3
2022	1	2	0	0	1
Citations total	*56*	*354*	*122*	*47*	*57*
Citations per year	*4.0*	*19.7*	*11.1*	*3.6*	*4.4*

The figure shows the distribution of citations per year and procedure model analyzed.



VI.7 Appendix B. Complete List of the Articles Analyzed and Classification Results

The table lists all references (636) that are analyzed regarding their in-text citations. The second column of the table indicates the cited procedure model publication (B09, D05, M12, S10, V10). The following columns contain the classification of the in-text citations according to their purpose into one of the following categories: citations placed for (C1) applying the procedure model for maturity model development, (C2) discussing/comparing the procedure model(s), or (C3) serving another purpose.

		Citation purpose		
Reference	**Article cited**	**Model application**	**Model discussion**	**Other purposes**
Albrecht, J. C., & Spang, K. (2016). Disassembling and Reassembling Project Management Maturity. *Project Management Journal*, *47*(5), 18–35.	B09		●	
Burger, A. J., Grobbelaar, S., & Sacks, N. (2020). A Scoping Review for the Development of a Maturity Framework for Advanced Manufacturing Technologies: The Case for Cemented Tungsten Carbides. In *Proceedings of the 29th International Conference of the International Association for Management of Technology*, virtual.	B09		●	
Butzer, S., Schötz, S., & Steinhilper, R. (2017). Remanufacturing Process Capability Maturity Model. *Procedia Manufacturing*, *8*, 715–722.	B09			●

Reference	Article cited	Citation purpose		
		Model application	Model discussion	Other purposes
Cleven, A., Winter, R., & Wortmann, F. (2012). Managing Process Performance to Enable Corporate Sustainability: A Capability Maturity Model. In J. vom Brocke, S. Seidel, & J. Recker (Eds.), *Green Business Process Management: Towards the Sustainable Enterprise* (pp. 111–129). Springer.	B09		●	●
Cosic, R., Shanks, G., & Maynard, S. (2012). Towards a Business Analytics Capability Maturity Model. In *Proceedings of the 23rd Australasian Conference on Information Systems,* Geelong, Australia.	B09	●	●	●
Cuenca, L., Boza, A., Alemany, M. d. M., & Trienekens, J. (2013). Structural Elements of Coordination Mechanisms in Collaborative Planning Processes and Their Assessment Through Maturity Models: Application to a Ceramic Tile Company. *Computers in Industry, 64*(8), 898–911.	B09		●	
de Sousa Pereira, R. F., & da Silva, M. M. (2010). A Maturity Model for Implementing ITIL v3. In *Proceedings of the 6th World Congress on Services,* Miami, United States of America.	B09			●
Domingues, P., Sampaio, P., & Arezes, P. M. (2013). Integrated Management Systems: A Statistical Analysis. In *Proceedings of the International Symposium on Occupational Safety and Hygiene,* Guimarães, Portugal.	B09			●
Domingues, P., Sampaio, P., & Arezes, P. M. (2016). Integrated Management Systems Assessment: A Maturity Model Proposal. *Journal of Cleaner Production, 124*, 164–174.	B09		●	

Reference	Article cited	Citation purpose: Model application	Model discussion	Other purposes
Duque, S. E., & El-Thalji, I. (2020). Intelligent Maintenance Maturity of Offshore Oil and Gas Platform: A Customized Assessment Model Complies with Industry 4.0 Vision. In J. P. Liyanage, J. Amadi-Echendu, & J. Mathew (Eds.), *Lecture Notes in Mechanical Engineering, Engineering Assets and Public Infrastructures in the Age of Digitalization: Proceedings of the 13th World Congress on Engineering Asset Management* (pp. 653–663). Springer.	B09	●		●
Englbrecht, L., Meier, S., & Pernul, G. (2020). Towards a Capability Maturity Model for Digital Forensic Readiness. *Wireless Networks, 26*(7), 4895–4907.	B09		●	
Enke, J., Metternich, J., Bentz, D., & Klaes, P.-J. (2018). Systematic Learning Factory Improvement Based on Maturity Level Assessment. *Procedia Manufacturing, 23*, 45–50.	B09		●	
Felch, V., & Asdecker, B. (2020). How to Make Business Process Maturity Models Better – Drawing on Design Science Research. In *Proceedings of the 24th Pacific Asia Conference on Information Systems,* virtual.	B09		●	●
Felch, V., & Asdecker, B. (2020). Quo Vadis, Business Process Maturity Model? Learning from the Past to Envision the Future. In D. Fahland, C. Ghidini, J. Becker, & M. Dumas (Eds.), *Lecture Notes in Computer Science: Vol. 12168, Business Process Management* (pp. 368–383). Springer.	B09		●	●

Reference	Article cited	Citation purpose: Model application	Citation purpose: Model discussion	Citation purpose: Other purposes
Felch, V., Asdecker, B., & Sucky, E. (2019). Maturity Models in the Age of Industry 4.0 – Do the Available Models Correspond to the Needs of Business Practice? In *Proceedings of the 52nd Hawaii International Conference on System Sciences,* Grand Wailea, United States of America.	B09			●
Fischer, C., & Brunnhofer, M. (2019). Maturity Model for Service Engineering. *Tehnicki Vjesnik, 26*(6), 1554–1561.	B09			●
Frick, N., & Schubert, P. (2011). A Maturity Model for B2B Integration (BIMM). In *Proceedings of the 24th Bled eConference: eFuture: Creating Solutions for the Individual, Organisations and Society,* Bled, Slovenia.	B09	●	●	
García-Mireles, G. A., Ángeles Moraga, M. Á., & García, F. (2012). Development of Maturity Models: A Systematic Literature Review. In *Proceedings of the 16th International Conference on Evaluation & Assessment in Software Engineering,* Ciudad Real, Spain.	B09		●	●
Gochermann, J., & Nee, I. (2019). The Idea Maturity Model – A Dynamic Approach to Evaluate Idea Maturity. *International Journal of Innovation and Technology Management, 16*(5).	B09		●	
Goncalves Filho, A. P., & Waterson, P. (2018). Maturity Models and Safety Culture: A Critical Review. *Safety Science, 105*, 192–211.	B09			●

Reference	Article cited	Citation purpose: Model application	Citation purpose: Model discussion	Citation purpose: Other purposes
Hain, S., & Back, A. (2011). Towards a Maturity Model for E-Collaboration – A Design Science Research Approach. In *Proceedings of the 44th Hawaii International Conference on System Sciences,* Koloa, United States of America.	B09	●	●	●
Hajoary, P. K., & Akhilesh, K. B. (2021). Conceptual Framework to Assess the Maturity and Readiness Towards Industry 4.0. In A. Chakrabarti & M. Arora (Eds.), *Lecture Notes in Mechanical Engineering, Industry 4.0 and Advanced Manufacturing: Proceedings of I-4AM 2019* (pp. 13–23). Springer.	B09			●
Ilvarianto, D. S., & Legowo, N. (2017). Incident Management Implementation Using Continual Service Improvement Method at PT AOP. In *Proceedings of the International Conference on Applied Computer and Communication Technologies,* Jakarta, Indonesia.	B09			●
Janiesch, C., Korthaus, A., & Rosemann, M. (2009). Conceptualisation and Facilitation of SOA Governance. In *Proceedings of the 12th Australian Conference on Knowledge Management and Intelligent Decision Support and 20th Australasian Conference on Information Systems,* Melbourne, Australia.	B09			●
Knolmayer, G. F., Helfenstein, L. E., Loosli, G., & Disterer, G. W. (2012). Email Governance: Are Companies in Financial Industries More Mature? In *Proceedings of the 45th Hawaii International Conference on System Sciences,* Wailea, United States of America.	B09			●

Reference	Article cited	Citation purpose: Model application	Citation purpose: Model discussion	Citation purpose: Other purposes
Lattanzio, S., Carey, E., Hultin, A., Imani Asrai, R., Nassehi, A., Parry, G., & Newnes, L. (2021). The Transdisciplinary Engineering Index: Towards a Disciplinary Maturity Grid. In *Proceedings of the 28th International Conference on Transdisciplinary Engineering,* virtual.	B09		●	●
Leyh, C., Schäffer, T., Bley, K., & Forstenhäusler, S. (2017). Assessing the IT and Software Landscapes of Industry 4.0-enterprises: The Maturity Model SIMMI 4.0. In E. Ziemba (Ed.), *Information Technology for Management: New Ideas and Real Solutions* (Vol. 277, pp. 103–119). Springer.	B09	●	●	●
Mendes, P., Leal, J. E., & Thomé, A. M. T. (2016). A Maturity Model for Demand-driven Supply Chains in the Consumer Product Goods Industry. *International Journal of Production Economics, 179,* 153–165.	B09		●	
Niewöhner, N., Lang, N., Asmar, L., Röltgen, D., Kühn, A., & Dumitrescu, R. (2021). Towards an Ambidextrous Innovation Management Maturity Model. *Procedia CIRP, 100,* 289–294.	B09			●
Niknam, M., & Ovtcharova, J. (2013). Towards Higher Configuration Management Maturity. In A. Bernard, L. Rivest, & D. Dutta (Eds.), *Product Lifecycle Management for Society* (Vol. 409, pp. 396–405). Springer.	B09			●
Nord, F., Dorbecker, R., & Bohmann, T. (2016). Structure, Content and Use of IT Service Catalogs – Empirical Analysis and Development of a Maturity Model. In *Proceedings of the 49th Hawaii International Conference on System Sciences,* Koloa, United States of America.	B09	●	●	●

Reference	Article cited	Citation purpose: Model application	Citation purpose: Model discussion	Citation purpose: Other purposes
Pappel, I [Ingmar], Gelashvili, T., & Pappel, I [Ingrid] (2022). Maturity Model for Automatization of Service Provision and Decision-Making Processes in Municipalities. In *Proceedings of the 7th International Congress on Information and Communication Technology,* London, United Kingdom.	B09			●
Pereira, R., & da Silva, M. M. (2011). A Maturity Model for Implementing ITIL V3 in Practice. In *Proceedings of the 15th International Enterprise Distributed Object Computing Conference Workshops,* Helsinki, Finland.	B09			●
Proença, D., & Borbinha, J. (2017). Enterprise Architecture: A Maturity Model Based on TOGAF ADM. In *Proceedings of the 19th Conference on Business Informatics,* Thessaloniki, Greece.	B09	●	●	
Proença, D., Estevens, J., Vieira, R., & Borbinha, J. (2017). Risk Management: A Maturity Model Based on ISO 31000. In *Proceedings of the 19th Conference on Business Informatics,* Thessaloniki, Greece.	B09	●	●	●
Proença, D., & Borbinha, J. (2016). Maturity Models for Information Systems – A State of the Art. *Procedia Computer Science, 100,* 1042–1049.	B09		●	●
Proença, D., & Borbinha, J. (2018). Information Security Management Systems – A Maturity Model Based on ISO/IEC 27001. In W. Abramowicz & A. Paschke (Eds.), *Lecture Notes in Business Information Processing, Business Information Systems* (pp. 104–114). Springer.	B09	●	●	●

Reference	Article cited	Citation purpose: Model application	Model discussion	Other purposes
Proença, D., & Borbinha, J. (2018). Maturity Models for Data and Information Management: A State of the Art. In E. Méndez, F. Crestani, C. Ribeiro, G. David, & J. C. Lopes (Eds.), *Lecture Notes in Computer Science, Digital Libraries for Open Knowledge* (pp. 81–93). Springer.	B09			●
Proença, D., & Borbinha, J. (2019). Information Governance Maturity Assessment Using Enterprise Architecture Model Analysis and Description Logics. In A. Doucet, A. Isaac, K. Golub, T. Aalberg, & A. Jatowt (Eds.), *Lecture Notes in Computer Science, Digital Libraries for Open Knowledge* (pp. 265–279). Springer.	B09	●	●	
Proença, D., & Borbinha, J. (2020). Maturity Assessment of TOGAF ADM Using Enterprise Architecture Model Analysis and Description Logics. In D. Aveiro, G. Guizzard, & J. Borbinha (Eds.), *Lecture Notes in Business Information Processing, Advances in Enterprise Engineering XIII* (pp. 115–134). Springer.	B09	●	●	
Proença, D., Vieira, R., & Borbinha, J. (2017). Information Governance Maturity Model Final Development Iteration. In J. Kamps, G. Tsakonas, Y. Manolopoulos, L. Iliadis, & I. Karydis (Eds.), *Lecture Notes in Computer Science, Research and Advanced Technology for Digital Libraries* (pp. 128–139). Springer.	B09	●	●	
Renault, A., Cortina, S., & Barafort, B. (2015). Towards a Maturity Model for ISO/IEC 20000-1 Based on the TIPA for ITIL Process Capability Assessment Model. In T. Rout, R. V. O'Connor, & A. Dorling (Eds.), *Communications in Computer and Information Science, Software Process Improvement and Capability Determination* (pp. 188–200). Springer.	B09		●	

Reference	Article cited	Citation purpose: Model application	Citation purpose: Model discussion	Citation purpose: Other purposes
Rohner, P. (2013). Identity Management for Health Professionals: A Method for the Integration of Responsibility, Organization, and IT. *Business and Information Systems Engineering, 5*(1), 17–33.	B09			●
Santiago Rivera, D., & Shanks, G. (2015). A Dashboard to Support Management of Business Analytics Capabilities. *Journal of Decision Systems, 24*(1), 73–86.	B09			●
Schäffer, T., Leyh, C., Bley, K., & Schimmele, M. (2018). Towards an Open Ecosystem for Maturity Models in the Digital Era: The Example of the Data Quality Management Perspective. In *Proceedings of the 24th Americas Conference on Information Systems,* New Orleans, United States of America.	B09		●	●
Schreckenberg, F., & Moroff, N. U. (2021). Developing a Maturity-based Workflow for the Implementation of ML-applications Using the Example of a Demand Forecast. *Procedia Manufacturing, 54*, 31–38.	B09	●		
Schumacher, A., Erol, S., & Sihn, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP, 52*, 161–166.	B09	●		
Siedler, C., Dupont, S., Zavareh, M. T., Zeihsel, F., Ehemann, T., Sinnwell, C., Göbel, J. C., Zink, K. J., & Aurich, J. C. (2021). Maturity Model for Determining Digitalization Levels Within Different Product Lifecycle Phases. *Production Engineering, 15*(3-4), 431–450.	B09	●		
Spalek, S. (2014). Finding a New Way to Increase Project Management Efficiency in Terms of Time Reduction. *Engineering Economics, 25*(5), 538–548.	B09			●

Reference	Article cited	Citation purpose: Model application	Model discussion	Other purposes
Stallinger, F., & Plösch, R. (2014). Towards Methodological Support for the Engineering of Process Reference Models for Product Software. In A. Mitasiunas, T. Rout, R. V. O'Connor, & A. Dorling (Eds.), *Communications in Computer and Information Science, Software Process Improvement and Capability Determination* (pp. 24–35). Springer.	B09		●	
Sütőová, A., Šooš, Ľ., & Kóča, F. (2020). Learning Needs Determination for Industry 4.0 Maturity Development in Automotive Organisations in Slovakia. *Quality Innovation Prosperity, 24*(3), 122–139.	B09	●		
von Wangenheim, C. G., von Wangenheim, A., Hauck, J. C. R., McCaffery, F., & Buglione, L. (2012). Tailoring Software Process Capability/Maturity Models for Telemedicine Systems. In *Proceedings of the 18th Americas Conference on Information Systems,* Seattle, United States of America.	B09			●
Weckenmann, A., & Akkasoglu, G. (2012). Maturity Model for the Development of New Forming Processes Applied to the Sheet-bulk Metal Forming. *Key Engineering Materials, 504-506,* 1011–1016.	B09		●	
Weckenmann, A., & Akkasoglu, G. (2013). Methodic Design of a Customized Maturity Model for Geometrical Tolerancing. *Procedia CIRP, 10,* 119–124.	B09		●	
Wißotzki, M., & Koç, H. (2013). A Project Driven Approach for Enhanced Maturity Model Development for EAM Capability Evaluation. In *Proceedings of the 17th International Enterprise Distributed Object Computing Conference Workshops,* Vancouver, Canada.	B09	●	●	●

Reference	Article cited	Citation purpose: Model application	Citation purpose: Model discussion	Citation purpose: Other purposes
Zschech, P., Heinrich, K., Pfitzner, M., & Hilbert, A. (2017). Are You Up for the Challenge? Towards the Development of a Big Data Capability Assessment Model. In *Proceedings of the 25th European Conference on Information Systems,* Guimarães, Portugal.	B09	●	●	●
Abdul Latif, A., Habibah Arshad, N., & Janom, N. (2020). Towards an Infostructure Maturity Model for Disaster Management. In *Proceedings of the 8th International Conference on Information Technology and Multimedia,* Selangor, Malaysia.	D05			●
Acartürk, C., Ulubay, M., & Erdur, E. (2021). Continuous Improvement on Maturity and Capability of Security Operation Centres. *IET Information Security, 15*(1), 59–75.	D05			●
Acerbi, F., Assiani, S., & Taisch, M. (2019). A Methodology to Assess the Skills for an Industry 4.0 Factory. In F. Ameri, K. E. Stecke, G. von Cieminski, & D. Kiritsis (Eds.), *IFIP Advances in Information and Communication Technology, Advances in Production Management Systems. Towards Smart Production Management Systems* (pp. 520–527). Springer.	D05	●		●
Acerbi, F., Järnefelt, V., Martins, J. T., Saari, L., Valkokari, K., & Taisch, M. (2021). Developing a Qualitative Maturity Scale for Circularity in Manufacturing. In A. Dolgui, A. Bernard, D. Lemoine, G. von Cieminski, & D. Romero (Eds.), *IFIP Advances in Information and Communication Technology, Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems* (pp. 377–385). Springer.	D05	●		

Reference	Article cited	Citation purpose: Model application	Citation purpose: Model discussion	Citation purpose: Other purposes
Adrodegari, F., & Saccani, N. (2020). A Maturity Model for the Servitization of Product-centric Companies. *Journal of Manufacturing Technology Management, 31*(4), 775–797.	D05			●
Aggour, A., Moussaid, A., & El Hassan, A. A. (2018). Fast Fashion Assessment Tool: A Case Study of a Moroccan Apparel Supply Chain. *International Journal of Supply Chain Management, 7*(5), 213–220.	D05	●	●	●
Aguiar, J., Pereira, R., de Vasconcelos, J. B., & Bianchi, I. (2018). An Overlapless Incident Management Maturity Model for Multi-framework Assessment (ITIL, COBIT, CMMI-SVC). *Interdisciplinary Journal of Information, Knowledge, and Management, 13,* 137–163.	D05			●
Aguiar, T., Gomes, S. B., da Cunha, P. R., & da Silva, M. M. (2019). Digital Transformation Capability Maturity Model Framework. In *Proceedings of the 23rd International Enterprise Distributed Object Computing Conference,* Paris, France.	D05			●
Alami, O. M., Bouksour, O., & Beidouri, Z. (2015). An Intelligent Project Management Maturity Model for Moroccan Engineering Companies. *Vikalpa: The Journal for Decision Makers, 40*(2), 191–208.	D05	●	●	●
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		Model application	Model discussion	Other purposes
Wißotzki, M., & Koç, H. (2014). Evaluation Concept of the Enterprise Architecture Management Capability Navigator. In *Proceedings of the 16th International Conference on Enterprise Information Systems,* Lisbon, Portugal.	S10			●
Zahrullaili, M. H., & Noordin, M. F. (2018). Towards Developing a Comprehensive Business Intelligence Maturity Model for Malaysian Public Sector: Application of Mixed Methodology. In *Proceedings of the 4th International Conference on Information Retrieval and Knowledge Management,* Kota Kinabalu, Malaysia.	S10			●
Zschech, P., Heinrich, K., Pfitzner, M., & Hilbert, A. (2017). Are You Up for the Challenge? Towards the Development of a Big Data Capability Assessment Model. In *Proceedings of the 25th European Conference on Information Systems,* Guimarães, Portugal.	S10		●	
Abdellatif, A., Alshayeb, M., Zahran, S., & Niazi, M. (2019). A Measurement Framework for Software Product Maturity Assessment. *Journal of Software: Evolution and Process, 31*(4).	V10			●
Akinsanya, O. O., Papadaki, M., & Sun, L. (2019). Current Cybersecurity Maturity Models: How Effective in Healthcare Cloud? In *Proceedings of the 5th Collaborative European Research Conference,* Darmstadt, Germany.	V10			●
Bakar, N. A. A., Harihodin, S., & Kama, N. (2017). A Priority Based Enterprise Architecture Implementation Assessment Model: An Analytic Hierarchy Process (AHP) Approach. *Journal of Telecommunication, Electronic and Computer Engineering, 9*(2-3), 121–125.	V10	●		

Reference	Article cited	Citation purpose		
		Model application	Model discussion	Other purposes
Bakar, N. A. A., Selamat, H., & Kama, M. N. (2017). Assessing the Capability and Priority of Enterprise Architecture Implementation in Malaysian Public Sector. In *Proceedings of the 21st Pacific Asia Conference on Information Systems,* Pulau Langkawi, Malaysia.	V10			●
Boehm, M., Jasper, M., & Thomas, O. (2013). The Further Education Maturity Model: Development and Implementation of a Maturity Model for the Selection of Further Education Offerings in the Field of IT Management and IT Consulting. In *Proceedings of the 19th Americas Conference on Information Systems,* Chicago, United States of America.	V10			●
Cleven, A., Winter, R., & Wortmann, F. (2012). Managing Process Performance to Enable Corporate Sustainability: A Capability Maturity Model. In J. vom Brocke, S. Seidel, & J. Recker (Eds.), *Green Business Process Management: Towards the Sustainable Enterprise* (pp. 111–129). Springer.	V10			●
Cruz, P., & Astudillo, H. (2020). Towards a Maturity Model for Assessment of Organization Readiness in Implementing and Deploying an Open Innovation Platform. In *Proceedings of the 16th International Symposium on Open Collaboration,* virtual.	V10			●
Cuenca, L., Boza, A., Alemany, M. d. M., & Trienekens, J. (2013). Structural Elements of Coordination Mechanisms in Collaborative Planning Processes and Their Assessment Through Maturity Models: Application to a Ceramic Tile Company. *Computers in Industry, 64*(8), 898–911.	V10		●	

Reference	Article cited	Citation purpose: Model application	Citation purpose: Model discussion	Citation purpose: Other purposes
de Carvalho, J. V., Pereira, R. H., & Rocha, Á. (2018). Development Methodology of a Higher Education Institutions Maturity Model. In *Proceedings of the 10th International Conference on Intelligent Networking and Collaborative Systems,* Bratislava, Slovakia.	V10		●	
dos Santos-Neto, J. B. S., & Costa, A. P. C. S. (2019). Enterprise Maturity Models: A Systematic Literature Review. *Enterprise Information Systems, 13*(5), 719–769.	V10			●
Drivas, G., Chatzopoulou, A., Maglaras, L., Lambrinoudakis, C., Cook, A., & Janicke, H. (2020). A NIS Directive Compliant Cybersecurity Maturity Assessment Framework. In *Proceedings of the 44th Annual Computers, Software, and Applications Conference,* Madrid, Spain.	V10			●
Felch, V., & Asdecker, B. (2020). How to Make Business Process Maturity Models Better – Drawing on Design Science Research. In *Proceedings of the 24th Pacific Asia Conference on Information Systems,* virtual.	V10			●
Felch, V., & Asdecker, B. (2020). Quo Vadis, Business Process Maturity Model? Learning from the Past to Envision the Future. In D. Fahland, C. Ghidini, J. Becker, & M. Dumas (Eds.), *Lecture Notes in Computer Science: Vol. 12168, Business Process Management* (pp. 368–383). Springer.	V10			●
García-Mireles, G. A., Ángeles Moraga, M. Á., & García, F. (2012). Development of Maturity Models: A Systematic Literature Review. In *Proceedings of the 16th International Conference on Evaluation & Assessment in Software Engineering,* Ciudad Real, Spain.	V10		●	●

Reference	Article cited	Citation purpose: Model application	Model discussion	Other purposes
Gollhardt, T., Halsbenning, S., Hermann, A., Karsakova, A., & Becker, J. (2020). Development of a Digital Transformation Maturity Model for IT Companies. In *Proceedings of the 22nd Conference on Business Informatics,* Antwerp, Belgium.	V10		●	●
Häckel, B., Huber, R. X. R., Stahl, B., & Stöter, M. (2021). Becoming a Product-Service System Provider – A Maturity Model for Manufacturers. In *Proceedings of the 16th International Conference on Wirtschaftsinformatik,* virtual.	V10	●		●
Hermans, M., Volker, L., & Eisma, P. (2014). A Public Commissioning Maturity Model for Construction Clients. In *Proceedings of the 30th Annual Association of Researchers in Construction Management Conference,* Portsmouth, United Kingdom.	V10	●		
Jansen, S. (2020). A Focus Area Maturity Model for Software Ecosystem Governance. *Information and Software Technology, 118.*	V10			●
Jin, D., Chai, K.-H., & Tan, K.-C. (2014). New Service Development Maturity Model. *Managing Service Quality, 24*(1), 86–116.	V10	●		●
Khanra, S., & Joseph, R. P. (2020). Development and Validation of an Assessment Framework for E-Government Services. In *Proceedings of the 7th International Conference on Electronic Governance and Open Society: Challenges in Eurasia,* St. Petersburg, Russia.	V10			●

Reference	Article cited	Citation purpose		
		Model application	Model discussion	Other purposes
Klötzer, C., & Pflaum, A. (2017). Toward the Development of a Maturity Model for Digitalization within the Manufacturing Industry's Supply Chain. In *Proceedings of the 50th Hawaii International Conference on System Sciences,* Waikoloa Village, United States of America.	V10			●
Lahrmann, G., Marx, F., Mettler, T., Winter, R., & Wortmann, F. (2011). Inductive Design of Maturity Models: Applying the Rasch Algorithm for Design Science Research. In H. Jain, A. P. Sinha, & P. Vitharana (Eds.), *Lecture Notes in Computer Science, Service-Oriented Perspectives in Design Science Research* (pp. 176–191). Springer.	V10			●
Lattanzio, S., Carey, E., Hultin, A., Imani Asrai, R., Nassehi, A., Parry, G., & Newnes, L. (2021). The Transdisciplinary Engineering Index: Towards a Disciplinary Maturity Grid. In *Proceedings of the 28th International Conference on Transdisciplinary Engineering,* virtual.	V10		●	
Lee, D., Gu, J.-W., & Jung, H.-W. (2019). Process Maturity Models: Classification by Application Sectors and Validities Studies. *Journal of Software: Evolution and Process, 31*(4), 1-30.	V10			●
Maier, A. M., Moultrie, J., & Clarkson, P. J. (2012). Assessing Organizational Capabilities: Reviewing and Guiding the Development of Maturity Grids. *IEEE Transactions on Engineering Management, 59*(1), 138–159.	V10		●	
Marx, F., Wortmann, F., & Mayer, J. H. (2012). A Maturity Model for Management Control Systems: Five Evolutionary Steps to Guide Development. *Business & Information Systems Engineering, 4*(4), 193–207.	V10		●	●

Reference	Article cited	Citation purpose		
		Model application	Model discussion	Other purposes
Mettler, T. (2011). Transformation of the Hospital Supply Chain: How to Measure the Maturity of Supplier Relationship Management Systems in Hospitals? *International Journal of Healthcare Information Systems and Informatics, 6*(2), 1–13.	V10			●
Mettler, T. (2013). Transformation of the Hospital Supply Chain: How to Measure the Maturity of Supplier Relationship Management Systems in Hospitals? In J. Tan (Ed.), *Healthcare Information Technology Innovation and Sustainability: Frontiers and Adoption* (pp. 180–192). IGI Global.	V10			●
Mijnhardt, F., Baars, T., & Spruit, M. (2016). Organizational Characteristics Influencing SME Information Security Maturity. *Journal of Computer Information Systems, 56*(2), 106–115.	V10			●
Ojo, A., Janowski, T., & Estevez, E. (2012). Improving Government Enterprise Architecture Practice – Maturity Factor Analysis. In *Proceedings of the 45th Hawaii International Conference on System Sciences,* Wailea, United States of America.	V10			●
Otto, L., Bley, K., & Harst, L. (2020). Designing and Evaluating Prescriptive Maturity Models: A Design Science-oriented Approach. In *Proceedings of the 22nd Conference on Business Informatics,* Antwerp, Belgium.	V10		●	
Pappel, I [Ingmar], Gelashvili, T., & Pappel, I [Ingrid] (2022). Maturity Model for Automatization of Service Provision and Decision-Making Processes in Municipalities. In *Proceedings of the 7th International Congress on Information and Communication Technology,* London, United Kingdom.	V10			●

Reference	Article cited	Citation purpose		
		Model application	Model discussion	Other purposes
Patas, J. (2012). Towards Maturity Models as Methods to Manage IT for Business Value – A Resource-based View Foundation. In *Proceedings of the 18th Americas Conference on Information Systems,* Seattle, United States of America.	V10			●
Patas, J. (2015). Developing Individual IT-enabled Capabilities for Management Control Systems. In J. H. Mayer & R. Quick (Eds.), *Business Intelligence for New-Generation Managers: Current Avenues of Development* (pp. 51–66). Springer.	V10			●
Patas, J., Pöppelbuß, J., & Goeken, M. (2013). Cherry Picking with Meta-Models: A Systematic Approach for the Organization-Specific Configuration of Maturity Models. In J. vom Brocke, R. Hekkala, S. Ram, & M. Rossi (Eds.), *Lecture Notes in Computer Science, Design Science at the Intersection of Physical and Virtual Design* (pp. 353–368). Springer.	V10		●	●
Peng, L., Feng, W., Chen, K [Kefu], & Li, C. (2016). Smart Manufacturing Capability Maturity Model: Connotation, Feature And Trend. In *Proceedings of the International Conference on Electronic Business,* Xiamen, China.	V10			●
Peng, L., Feng, W., Li, C., & Han, S. (2015). Research of E-commerce Enterprises Capability Maturity Theory and Initial Model Construction. In *Proceedings of the International Conference on Electronic Business,* Hong Kong, China.	V10			●

Reference	Article cited	Citation purpose		
		Model application	Model discussion	Other purposes
Pereira, R. H., de Carvalho, J. V., & Rocha, Á. (2020). Towards an Encompassing Maturity Model for the Management of Higher Education Institutions. *International Journal of Grid and Utility Computing, 11*(5), 587–601.	V10		●	
Raber, D., Epple, J., Winter, R., & Rothenberger, M. (2016). Closing the Loop: Evaluating a Measurement Instrument for Maturity Model Design. In *Proceedings of the 49th Hawaii International Conference on System Sciences,* Koloa, United States of America.	V10			●
Raber, D., Wortmann, F., & Winter, R. (2013). Towards the Measurement of Business Intelligence Maturity. In *Proceedings of the 21st European Conference on Information Systems,* Utrecht, The Netherlands.	V10			●
Sanchez-Puchol, F., & Pastor-Collado, J. A. (2017). Focus Area Maturity Models: A Comparative Review. In *Proceedings of the 14th European, Mediterranean, and Middle Eastern Conference on Information Systems,* Coimbra, Portugal.	V10		●	●
Sari, N. A., Hidayanto, A. N., Sandhyaduhita, P. I., Munajat, Q., & Phusavat, K. (2021). Impact of Enterprise Architecture Management on Business Benefits Through Information Technology Benefits in Companies in Indonesia. *International Journal of Business Information Systems, 36*(1), 71–97.	V10			●
Schäffer, T., Leyh, C., Bley, K., & Schimmele, M. (2018). Towards an Open Ecosystem for Maturity Models in the Digital Era: The Example of the Data Quality Management Perspective. In *Proceedings of the 24th Americas Conference on Information Systems,* New Orleans, United States of America.	V10			●

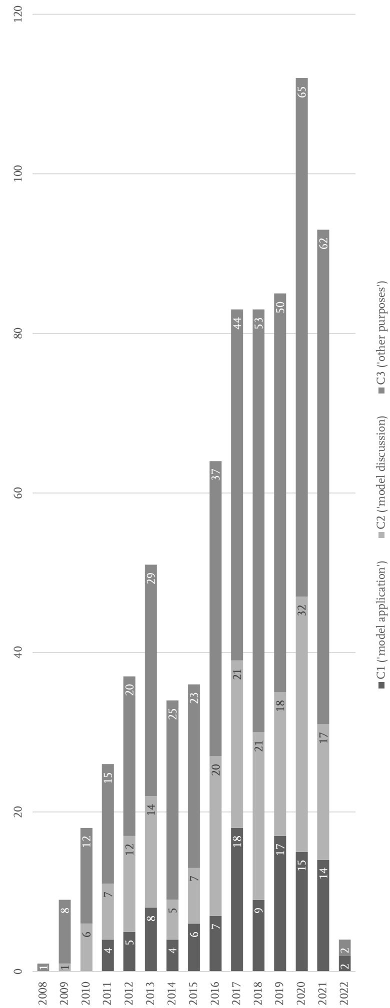
Reference	Article cited	Citation purpose		
		Model application	Model discussion	Other purposes
Simon, D., Fischbach, K., & Schoder, D. (2014). Enterprise Architecture Management and Its Role in Corporate Strategic Management. *Information Systems and E-Business Management, 12*(1), 5–42.	V10			●
Smits, D., & van Hillegersberg, J. (2014). The Development of an IT Governance Maturity Model for Hard and Soft Governance. In *Proceedings of the 8th European Conference on Information Management and Evaluation,* Ghent, Belgium.	V10	●		
Smits, D., & van Hillegersberg, J. (2015). IT Governance Maturity: Developing a Maturity Model Using the Delphi Method. In *Proceedings of the 48th Hawaii International Conference on System Sciences,* Koloa, United States of America.	V10	●		●
Spruit, M., & Roeling, M. (2014). ISFAM: The Information Security Focus Area Maturity Model. In *Proceedings of the 22nd European Conference on Information Systems,* Tel Aviv, Israel.	V10			●
Spruit, M., & Slot, G. (2017). ISFAM 2.0: Revisiting the Information Security Assessment Model. In M. Boskovic (Ed.), *Security Risks: Assessment, Management and Current Challenges* (pp. 87–108). Nova.	V10	●	●	●
Stallinger, F., & Plösch, R. (2014). Towards Methodological Support for the Engineering of Process Reference Models for Product Software. In A. Mitasiunas, T. Rout, R. V. O'Connor, & A. Dorling (Eds.), *Communications in Computer and Information Science, Software Process Improvement and Capability Determination* (pp. 24–35). Springer.	V10		●	

Reference	Article cited	Citation purpose		
		Model application	Model discussion	Other purposes
Stelzl, K., Röglinger, M., & Wyrtki, K. (2020). Building an Ambidextrous Organization: A Maturity Model for Organizational Ambidexterity. *Business Research, 13*(3), 1203–1230.	V10		●	●
Thakurta, R., Mueller, B., Ahlemann, F., & Hoffmann, D. (2017). The State of Design – A Comprehensive Literature Review to Chart the Design Science Research Discourse. In *Proceedings of the 50th Hawaii International Conference on System Sciences,* Waikoloa Village, United States of America.	V10			●
van der Waldt, G. (2013). Disaster Risk Management: Disciplinary Status and Prospects for a Unifying Theory. *Jamba: Journal of Disaster Risk Studies, 5*(2).	V10			●
van Looy, A., de Backer, M., & Poels, G. (2011). Questioning the Design of Business Process Maturity Models. In *Proceedings of the 6th SIKS Conference on Enterprise Information Systems,* Delft, The Netherlands.	V10			●
van Looy, A., de Backer, M., & Poels, G. (2012). Towards a Decision Tool for Choosing a Business Process Maturity Model. In K. Peffers, M. Rothenberger, & B. Kuechler (Eds.), *Lecture Notes in Computer Science: Vol. 7286, Design Science Research in Information Systems. Advances in Theory and Practice* (pp. 78–87). Springer.	V10			●
van Looy, A., Poels, G., & Snoeck, M. (2017). Evaluating Business Process Maturity Models. *Journal of the Association for Information Systems, 18*(6), 461–486.	V10			●

Reference	Article cited	Citation purpose: Model application	Model discussion	Other purposes
Yigit Ozkan, B., & Spruit, M. (2018). A Questionnaire Model for Cybersecurity Maturity Assessment of Critical Infrastructures. In *Proceedings of the 1st International Workshop on Information & Operational Technology (IT & OT) Security Systems,* Heraklion, Greece.	V10			●
Yigit Ozkan, B., Spruit, M., Wondolleck, R., & Burriel Coll, V. (2020). Modelling Adaptive Information Security for SMEs in a Cluster. *Journal of Intellectual Capital, 21*(2), 235–256.	V10			●

VI.8 Appendix C. Distribution of Citations per Year and Category

The figure shows the number of citations per year and category.



VI.9 Appendix D. Overview of Articles Applying a Procedure Model

The table contains the 109 articles that applied procedure model(s) for the development of maturity models (assigned to C1).

Article by	B09	D05	M12	S10	V10
Acerbi et al. (2021)		●			
Acerbi et al. (2019)		●			
Adamson et al. (2018)				●	
Aggour et al. (2018)		●			
Alami et al. (2015)		●			
Allais et al. (2017)			●		
Alsheibani et al. (2019)		●			
Antonsen and Madsen (2021)		●	●		
Asdecker and Felch (2018)		●			
Bakar et al. (2017)					●
Bensiek and Kühn (2012)		●			
Bensiek et al. (2012)		●			
Burggräf et al. (2020)		●			
Caiado et al. (2021)		●			
Chung et al. (2017)				●	
Chung et al. (2018)				●	
Comuzzi and Patel (2016)		●			
Cosic et al. (2012)	●				
Cuenca et al. (2013)		●			
Da Rosa and da Silva (2015)		●			
Daclin et al. (2018)		●			
De Carolis et al. (2017)		●			

Article by	B09	D05	M12	S10	V10
Deale et al. (2019)		●			
Dermentzi et al. (2016)				●	
Díaz-Piloneta et al. (2021)		●			
Duane and O'Reilly (2012)				●	
Duque and El-Thalji (2020)	●				
Enke et al. (2018)		●			
Frick and Schubert (2011)	●				
Frick et al. (2013)		●			
Frick (2012)		●			
Friedrich (2017)		●			
Gandhi et al. (2019)		●			
Gemke et al. (2021)		●			
Gochermann and Nee (2019)		●			
Gonzalez-Feliu et al. (2020)		●			
Gregori and Riedel (2020)		●			
Häckel et al. (2021)					●
Hain and Back (2011)	●				
Hermans et al. (2014)					●
Jääskeläinen and Roitto (2015)		●			
Jääskeläinen et al. (2020)		●			
Jacob and Teuteberg (2019)		●			
Jæger and Halse (2017)		●			
Jansen (2020)		●			
Jin et al. (2014)		●	●		●
Joblot et al. (2019)		●			
Johansson et al. (2019)		●			
Kerpedzhiev et al. (2019)		●			

Article by	B09	D05	M12	S10	V10
Klötzer and Pflaum (2017)		●			
Kwiatkowski and Chinowsky (2017)		●			
Lahrmann et al. (2011)		●			
Latif et al. (2021)		●			
Lees (2017)		●			
Lehmkuhl et al. (2013)		●			
Lentes et al. (2017)		●			
Leonard et al. (2019)		●			
Leyh et al. (2017)	●				
Litos and Evans (2015)			●		
Litos and Evans (2014)			●		
MacChi and Fumagalli (2013)		●			
Magdaleno et al. (2011)		●			
Niknam et al. (2013)		●			
Niknam and Ovtcharova (2013)		●			
Nord et al. (2016)	●				
O'Donovan et al. (2016)		●			
O'Kane et al. (2015)		●			
Ogunyemi et al. (2017)		●			
Overeem et al. (2021)		●			
Pan Nogueras et al. (2022)		●			
Pappel and Gelashvili (2022)		●			
Perales-Manrique et al. (2019)		●			
Poltronieri et al. (2017)		●			
Proença and Borbinha (2020)	●				
Proença and Borbinha (2019)	●				
Proença and Borbinha (2018)	●				

Article by	B09	D05	M12	S10	V10
Proença and Borbinha (2017)					
Proença et al. (2017a)	●				
Proença et al. (2017b)	●				
Rajh (2020)		●			
Renyi et al. (2020)		●			
Rohner (2013)		●			
Rukonić et al. (2019)		●			
Salhieh and Alswaer (2021)		●			
Santos and Martinho (2020		●			
Sari et al. (2020)		●			
Schreckenberg and Moroff (2021)	●				
Schrimpf et al. (2021)		●			
Schrimpf et al. (2016)		●			
Schumacher and Sihn (2020a)		●			
Schumacher and Sihn (2020b)		●			
Schumacher et al. (2019)		●			
Schumacher et al. (2016)	●				
Scremin et al. (2018)		●			
Siedler et al. (2021)	●	●			
Sinnwell et al. (2019).		●			
Smits and van Hillegersberg (2015)			●		●
Smits and van Hillegersberg (2014)			●		●
Spruit (2017)					●
Stenqvist et al. (2018)			●		
Storbjerg et al. (2016)			●		
Sütőová et al. (2020)	●				
Suzic and Forza (2021)			●		

Article by	**B09**	**D05**	**M12**	**S10**	**V10**
Thordsen and Bick (2020)		●		●	
Trautmann (2021)		●			
Walter et al. (2019)		●			
Warnecke et al. (2019)		●			
Wißotzki and Koç (2013)	●				
Zschech et al. (2017)	●				
Σ	*18*	*75*	*10*	*6*	*7*

VI.10 Appendix E. Overview of Industry 4.0 Maturity Models

The table lists all 24 Industry 4.0 maturity models (released since 2011) that were identified by Caiado et al. (2021).

Article by	**Procedure model**	**Other research methodology**	**No explicit reference**
Akdil, K. Y., Ustundag, A., & Cevikcan, E. (2018). Maturity and Readiness Model for Industry 4.0 Strategy. In A. Ustundag & E. Cevikcan (Eds.), *Industry 4.0: Managing The Digital Transformation* (pp. 61–94). Springer.			•
Asdecker, B., & Felch, V. (2018). Development of an Industry 4.0 Maturity Model for the Delivery Process in Supply Chains. *Journal of Modelling in Management, 13*(4), 840–883.	•		
Bibby, L., & Dehe, B. (2018). Defining and Assessing Industry 4.0 Maturity Levels – Case of the Defence Sector. *Production Planning & Control, 29*(12), 1030–1043.			•
Canetta, L., Barni, A., & Montini, E. (2018). Development of a Digitalization Maturity Model for the Manufacturing Sector. In *Proceedings of the 23rd International Conference on Engineering, Technology and Innovation,* Stuttgart, Germany.			•
Castor, N., Damberg, D., & Sjöborg, E. (2016). *MESA MOM Capability Maturity Level.* https://www.control.lth.se/fileadmin/control/Education/EngineeringProgram/FRTN20/2016/Report-mesa-mom-capability__1_.pdf			•

Article by	Procedure model	Other research methodology	No explicit reference
de Carolis, A., Macchi, M., Kulvatunyou, B., Brundage, M. P., & Terzi, S. (2017). Maturity Models and Tools for Enabling Smart Manufacturing Systems: Comparison and Reflections for Future Developments. In J. Ríos, A. Bernard, A. Bouras, & S. Foufou (Eds.), *Product Lifecycle Management and the Industry of the Future* (Vol. 517, pp. 23–35). Springer.			●
Ganzarain, J., & Errasti, N. (2016). Three Stage Maturity Model in SME's Toward Industry 4.0. *Journal of Industrial Engineering and Management, 9*(5), 1119–1128.			●
Gökalp, E., Şener, U., & Eren, P. E. (2017). Development of an Assessment Model for Industry 4.0: Industry 4.0-MM. In A. Mas, A.-L. Mesquida, R. V. O'Connor, T. Rout, & A. Dorling (Eds.), *Communications in Computer and Information Science, Software Process Improvement and Capability Determination* (pp. 128–142). Springer.			●
Jung, K., Kulvatunyou, B., Choi, S., & Brundage, M. P. (2016). An Overview of a Smart Manufacturing System Readiness Assessment. In I. Nääs, O. Vendrametto, J. Mendes Reis, R. F. Gonçalves, M. T. Silva, G. von Cieminski, & D. Kiritsis (Eds.), *Advances in Production Management Systems. Initiatives for a Sustainable World* (pp. 705–712). Springer.			●
Katsma, C. P., Moonen, H. M., & van Hillegersberg, J. (2011). Supply Chain Systems Maturing Towards the Internet-of-Things: A Framework. In *Proceedings of the 24th Bled eConference: eFuture: Creating Solutions for the Individual, Organisations and Society,* Bled, Slovenia.			●

Article by	Procedure model	Other research methodology	No explicit reference
Leineweber, S., Wienbruch, T., Lins, D., Kreimeier, D., & Kuhlenkötter, B. (2018). Concept for an Evolutionary Maturity Based Industrie 4.0 Migration Model. *Procedia CIRP*, *72*, 404–409.			•
Leyh, C., Schäffer, T., Bley, K., & Forstenhäusler, S. (2016). SIMMI 4.0 – A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0. In *Proceedings of the Federated Conference on Computer Science and Information Systems,* Gdansk, Poland.			•
Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E., & Schröter, M. (2015). *Impuls - Industrie 4.0 Readiness*. VDMA. http://www.impuls-stiftung.de/documents/3581372/4875835/Industrie+4.0+Readniness+IMPULS+Studie+Oktober+2015.pdf/447a6187-9759-4f25-b186-b0f5eac69974			•
Oleśków-Szłapka, J., & Stachowiak, A. (2019). The Framework of Logistics 4.0 Maturity Model. In A. Burduk, E. Chlebus, T. Nowakowski, & A. Tubis (Eds.), *Intelligent Systems in Production Engineering and Maintenance* (Vol. 835, pp. 771–781). Springer.			•
Pessl, E. (2017). Roadmap Industry 4.0 – Implementation Guideline for Enterprises. *International Journal of Science, Technology and Society*, *5*(6), 193.			•
PricewaterhouseCoopers. (2018). *Industry 4.0 – Enabling Digital Operations*. https://i40-self-assessment.pwc.de/i40/landing/			•

Article by	Procedure model	Other research methodology	No explicit reference
Qin, J., Liu, Y., & Grosvenor, R. (2016). A Categorical Framework of Manufacturing for Industry 4.0 and Beyond. *Procedia CIRP*, *52*, 173–178.			•
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Rübel, S., Emrich, A., Klein, S., & Loos, P. (2018). A Maturity Model for Business Model Management in Industry 4.0. In *Proceedings of the Multikonferenz Wirtschaftsinformatik,* Lüneburg, Germany.	•		
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Article by	Procedure model	Other research methodology	No explicit reference
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Article VII. Back to the Roots – Investigating the Theoretical Foundations of Business Process Maturity Models

Authors. Vanessa Felch and Björn Asdecker

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Abstract. For years, doubts have been raised about the usefulness of business process maturity models (BPMMs). In addition to methodological shortcomings and limited applicability of the models, another frequently voiced critique is a weak theoretical foundation. This conceptual paper analyzes previously released BPMMs and the related literature. It shows that the vast majority of articles do not refer to any theory to clarify the general underlying assumptions of the models. Instead, they resort to other existing models. In addition, the suitability of the few theoretical approaches to which some authors have referred is highly questionable. A further comparison of the theories' suitability issues with some of the fundamental criticisms of BPMMs reveals remarkable parallels. Against this background, the article at hand creates awareness of the need to consciously select and document the theoretical foundations of future BPMMs. In addition, it contributes to the epistemological discussion on BPMMs, how to evolve and improve the development of maturity models.

Keywords. Business Process · Business Process Management · Maturity Model · Theoretical Foundation · Theory

VII.1 Introduction

In recent years, numerous business process maturity models (BPMMs) have been developed and published in response to ever-expanding practical interest (Pöppelbuß & Röglinger, 2011; Rosemann, 2015). Likewise, doubts about the quality and usefulness of specific models have increased. The first documented concern dates to 2007, when de Bruin and Rosemann (2007, p. 644) critically commented that "[...] a number of available models appear to be 'power-point deep' in that they are proprietary in nature, have not been rigorously developed and tested, and are not supported by tools that enable them to be applied within a wide range of organizations". Subsequently, other authors, e.g., Pöppelbuß and Röglinger (2011) and van Looy (2014), joined this critique and repeatedly pointed out the varying quality of specific BPMMs. Tarhan et al. (2016) conducted a comprehensive literature review and, in line with previous observations, expressed doubts about the usefulness of several BPMMs.

Felch and Asdecker (2020) took note of the growing critique and examined whether this perception can actually be substantiated. Their analysis followed the premise that, in academia, the quality of the published model would be reflected in the quality of the publication outlet. They considered BPMMs published between 1990 and 2019 and used journal impact factors as a quality indicator. The results showed that "[...] articles about BPMMs are published in less-recognized journals, which are of minor relevance in the scientific community" (Felch & Asdecker, 2020, p. 373). This finding was attributed to methodological shortcomings and the models' limited usefulness and applicability. In addition, the authors stressed that "[...] there may be other reasons for not publishing BPMMs in higher quality journals" (Felch & Asdecker, 2020, p. 379).

This article focuses on the theoretical foundation of these BPMMs, another essential criterion for high-quality publications (Bornmann et al., 2008; Straub, 2009; Sutton & Staw, 1995). We understand a theoretical foundation as the perspective that establishes the common ground for the investigation and provides the lens through which researchers contribute to their research questions. Previous research has occasionally criticized the poor theoretical grounding of BPMMs (e.g., Niehaves et al., 2013, van Looy, 2014). However, a systematic analysis has not yet taken place. To (1) investigate whether a lack of theoretical grounding corresponds to individual cases or is rather the common rule and (2) propose ways of improving the current situation, we address the following two research questions:

RQ1: Are the existing BPMMs theoretically grounded, and if so, how?

RQ2: Are the currently used theoretical approaches suitable?

Methodologically, this study systematically reviews the literature to show that the vast majority of BPMM articles do not refer to any theory. Based on this surprising observation, abductive reasoning leads to the conclusion that some of the fundamental criticisms of those models can be attributed to the weaknesses of the few theoretical lenses that have been employed. Over a decade ago, Becker et al. (2010, p. 9) called for more work that takes a "critical perspective on maturation". Responding to this call for research, the contribution of this paper is threefold: First, it creates awareness of the need to deliberately choose and document the theoretical foundation of future BPMMs. Second, it highlights the shortcomings of previous theoretical foundations and argues that these may explain some of the fundamental criticisms of BPMMs. Third, it provides ideas for alternative theoretical foundations and proposes potential avenues on how to evolve BPMMs. Thus, this conceptual paper adds to the epistemological discussion on how to evolve and improve BPMM design in particular and maturity model design in general.

VII.2 Why a Solid Theoretical Foundation Is Necessary and Useful – Even in Practitioner-oriented Domains

While a theoretical foundation is widely considered necessary for empirical work, this is less obvious for other studies – particularly if they have strong roots in business practice. Therefore, it is necessary to demonstrate why a solid theoretical foundation is needed even in practitioner-oriented domains such as BPMM research.

In general, a theory is an evidence-based "[...] system composed of two core constituents: (1) constructs or concepts and (2) propositions as relationships between those constructs" (Müller & Urbach, 2013, p. 4). Theories either are the result of original research or form the basis for new research (Müller & Urbach, 2017). In the latter case, this is usually referred to as the theoretical foundation or theoretical grounding. The theoretical foundation serves multiple purposes. Most notably, it provides scholars with (1) the explicit assumptions and boundaries of the research and (2) the key variables and their interrelationships that describe the phenomenon of interest (Gregor, 2006; Müller & Urbach, 2017). In metaphorical terms, the role of the theoretical foundation is similar to the building's bedrock or the body's skeleton.

By combining the main goals of theories, Gregor (2006) distinguished five types: theories for (1) analysis, (2) explanation, (3) prediction, (4) explanation & prediction, and (5) design & action. Types 1–4 provide well-grounded insights into a phenomenon under investigation. In most cases, maturity models assume that organizations' capabilities mature in predefined stages and that progressing toward higher stages is better. However, such assumptions are merely proposed hypotheses that require empirical evaluations to be considered as theory (types 1–4). Type 5, in contrast, relates to method development by providing explicit specifications for the construction of an artifact. For BPMMs, which are considered an artifact, various procedure models and design guidelines exist (e.g., Becker et al., 2009, de Bruin et al., 2005, Pöppelbuß & Röglinger, 2011). These models and guidelines can be categorized as type 5. However, the study at hand focuses on types 1–4, which provide the basic assumptions about how organizations and processes evolve and how BPMMs actually work.

Counterintuitive to the term, theories always contain a practical side, suggesting how something should be done. Gregor (2006, p. 613) summarized that theories "[...] are practical because they allow knowledge to be accumulated in a systematic manner and this accumulated knowledge enlightens professional practice". The application of theories is helpful to researchers and practitioners alike (Gregor, 2006; Müller & Urbach, 2017). Through theory, researchers can better describe, explain, or predict the phenomena under study (Müller & Urbach, 2017). Especially in practitioner-oriented domains, theories serve as a guide to determine which assumptions and variables should be considered when structuring and designing management tools, such as BPMMs, to reach more informed and efficient decisions (Corley & Gioia, 2011; Dankasa, 2015; Gottschalk & Solli-Sæther, 2009; Lynham, 2002; Müller & Urbach, 2017). Consequently, top-tier outlets require a theoretical foundation in articles (Bornmann et al., 2008; Corley & Gioia, 2011; Rosemann et al., 2010; Straub, 2009). Straub and Ang (2008, p. viii) strongly supported this approach and therefore recommended to practice: "Rather than prescribing 'snake oil,' and 'untested management miracle-cures' (Pfeffer and Sutton 2006a, p. 1), practitioners should judiciously adopt only evidence-based management prescriptions derived from scientifically based evidence culled from carefully conducted social science and organizational research".

Regarding BPMMs, Niehaves et al. (2013) and van Looy (2014) have noted a weak theoretical foundation. This is surprising since the common basis of all maturity models is the assumption of predictable patterns in terms of organizational change, which in all circumstances requires some kind of theory. The question of if and how this has been done is the core of a systematic literature review presented in the following section.

VII.3 Current Theoretical Foundations of BPMMs

Several systematic reviews have analyzed the research on BPMMs, of which the most comprehensive one is by Tarhan et al. (2016). Their review focused on academic journals, conference proceedings, and books published between 1990 and 2014. This study was recently expanded by Felch and Asdecker (2020), using the same search terms and databases to address the latest BPMM developments (2015–2019). Together, both reviews identified 130 relevant BPMM references, of which 25 were released models. While investigating the theoretical foundation of those BPMMs (Sect. VII.3.1), we found only a few that referred to an actual theory, which motivated a broader systematic literature review (Sect. VII.3.2). Before presenting the literature search results, it is necessary to point out that few scholars have considered BPMMs as theory. For instance, Röglinger et al. (2012, p. 330) noted that such models "[...] typically represent theories about how an organization's capabilities evolve in a stage-by-stage manner along an anticipated, desired, or logical path". Referring to another BPMM could thus be considered an appropriate theoretical foundation. While acknowledging this perspective, we still disagree. Most notably, such an implicit approach would require a backward search that would contradict the basic scientific principles of clarity, transparency, and reproducibility. Moreover, many maturity models lack sufficient evidence, especially when newly designed. Thus, an essential component of a scientific theory is missing.

VII.3.1 Review of Theories Serving as Base for Released BPMMs

To investigate the theoretical grounding, we analyzed 25 BPMMs classified as 'release' according to the literature reviews by Tarhan et al. (2016) and Felch and Asdecker (2020) (see supplementary material A). Both initial model developments and refinements were among the 25 articles. In this case, each paper was analyzed separately (cf. Heinze & Geers, 2009, Jochem et al., 2011, Rosemann & de Bruin, 2005, Rosemann et al., 2004). In the case of almost complete textual consistency (cf. Rohloff, 2009a, 2009b, 2009c, 2010), only the most detailed article (Rohloff, 2010, incl.

supplementary electronic material) was included in the analysis. We examined the sections of the remaining contributions preceding the BPMM design. The analysis shows that previous articles paid little attention to the theoretical foundation prior to model development (see supplementary material B). Instead, various papers compared outstanding or thematically appropriate models (e.g., Chaghooshi et al., 2016, Lee et al., 2007), described the model purpose (e.g., Moradi-Moghadam et al., 2013, Zwicker et al., 2010), and/or presented definitions for the terms 'maturity' or 'maturity model' (e.g., Jadhav & Sapre, 2009, Jochem et al., 2011). Only one article, Chaghooshi et al. (2016), referred to Nolan (1973)'s stage theory.

Overall, the results provide a strong indication that existing BPMMs are rarely embedded in theories. Instead, the vast majority of scholars simply reviewed the literature to identify thematically related models while highlighting their weaknesses, which – in turn – were then used to justify the newly developed model (cf. de Bruin & Rosemann, 2007, Niehaves et al., 2013). While this step is explicitly required by various procedure models (cf. Becker et al., 2009, de Bruin et al., 2005), it does not constitute a theoretical foundation as such. The analysis confirms the views by Niehaves et al. (2013), van Looy (2014), and Pöppelbuß et al. (2011, p. 511), who stated that "[...] the design of maturity models has been too often informed by existing models (e.g., the CMM and CMMI) instead of applying these meaningful theoretical approaches". This preliminary finding motivated a more comprehensive analysis of the existing BPMM literature presented in the following section.

VII.3.2 Search of Potential Theories for BPMMs

To identify relevant articles, the search string ("BPMM" OR ("business process" AND "maturity model")) AND ("theory" OR "theories" OR "theoretical" OR "foundation") was used in the title, abstract, and keywords within four scientific databases: Business Source Ultimate via EBSCO, ScienceDirect, Scopus, and Web of Science. The initial search results were screened by applying the following selection criteria. First, only English publications were considered. Second, the results were limited to articles in journals, conference proceedings, and books. A total of 160 references were retrieved (see Table VII.1).

Digital library	EBSCO	Science Direct	Scopus	Web of Science
Initially retrieved	8	5	61	86
Initially selected	7	4	30	34
Duplicates removed		49		
Finally selected		5		

Table VII.1. Search string results and selection process

After reviewing the title, abstract, and keywords, 85 studies were excluded. These include articles that were not within the scope of this study, e.g., that dealt with BPMMs only incidentally or in which the abbreviation BPMM referred to another term. Subsequently, 26 duplicate studies were removed, and the remaining 49 articles were screened based on their full text (see supplementary material C). Papers that did not address the model grounding or potential theoretical approaches were excluded from further analysis. Despite this comprehensive search, the results were again surprisingly sparse. Only five articles referred to any theory: (1) Niehaves et al. (2013), (2) Niehaves et al. (2014), (3) Pöppelbuß et al. (2015), (4) Tapia et al. (2008), and (5) van Looy et al. (2011). Among those five papers, four used process life-cycle theory, and two considered convergence theory (see Table VII.2). Along with the article by Chaghooshi et al. (2016) identified during the review of the released BPMMs (Sect. VII.3.1), it leads to three theoretical approaches that have been referred to. Table VII.2 summarizes the results.

Overall, the findings of this additional literature search reinforce the impression that the theoretical foundation of BPMMs can be considered weak thus far. None of the publications explicitly addressed the underlying assumptions of the models. Instead, scholars usually resorted to other existing models. This presses the question of how appropriate the few theories mentioned are, which is addressed in the next section.

Article by	**Convergence theory** (Meyer et al., 1975)	**Process life-cycle theory** (van de Ven & Poole, 1995)	**Stage theory** (Nolan, 1973)
Chaghooshi et al. (2016)			●
Niehaves et al. (2013)	●		
Niehaves et al. (2014)		●	
Pöppelbuß et al. (2015)	●	●	
Tapia et al. (2008)		●	
van Looy et al. (2011)		●	

Table VII.2. Overview of the theories identified

VII.4 A Closer Look at the Theoretical Approaches Identified

Before evaluating the theoretical approaches, they are briefly introduced in the following. The discussion is limited to the key propositions due to page limitations.

VII.4.1 Introduction to the Theories

Convergence theory, process life-cycle theory, and stage theory suggest that change is imminent and occurs along a predefined path. This commonality becomes apparent when the core statements of the theories are juxtaposed.

Convergence Theory. The theory posits that the social structures of nations tend to align increasingly as industrialization progresses (Williamson & Fleming, 1977). Initial differences can be attributed to cultural, political, or economic aspects (Mishra, 1973), which later converge due to technological and economic constraints during industrialization. In general, convergence theory assumes that all entities of the same class move toward a general model or an ideal state (Pöppelbuß et al., 2015; Schmitt & Starke, 2011).

Process Life-Cycle Theory. Not to be confused with the homonymous theory from economics that describes people's spending and saving habits over a lifetime, the process life-cycle theory explains how entities develop and evolve (van de Ven & Poole, 1995). The theory assumes that entities develop linearly and irreversibly along a predefined sequence of phases (or stages) toward an optimal final state (Niehaves et al., 2014; Nielsen, 2008; Sabherwal et al., 2001; van de Ven & Poole, 1995). The driving mechanism is "[...] a prefigured program/rule regulated by nature, logic, or institutions" (van de Ven & Poole, 1995, p. 514).

Stage Theory. The theory originates from the model developed by Nolan (1973) in the 1970s, which describes the development of IT in organizations in four, later six (Nolan, 1979), stages (Solli-Sæther & Gottschalk, 2010). Stage theory generally proposes a stepwise development of an entity along a predefined and logical path (Nolan, 1973). The stages to be passed through are described by a distinctive set of attributes and the relationships among those attributes. Each stage builds on the previous one (Nolan, 1973).

In summary, there are considerable overlaps between the theories. Unlike the other two, convergence theory has its roots in sociology and does not specifically refer to organizations or processes (Williamson & Fleming, 1977). This is also supported by Niehaves et al. (2013, p. 224), who stated that "[...] this perspective is not suitable for the development of BPM and dynamic capabilities in general". Therefore, the convergence theory is excluded from further consideration. The core statements of the process life-cycle theory and stage theory tend to be quite similar, enhanced by several researchers who characterize stage theory as life-cycle theory (Nielsen, 2008; Sabherwal et al., 2001). However, the question of whether these theories are a suitable theoretical foundation for the development of BPMMs remains open. Therefore, the following section pursues an evaluation.

VII.4.2 Evaluation of the Theories

To date, there is no generally accepted procedure for evaluating the suitability of theories. However, Gieseler et al. (2019) suggest six criteria to assess the quality of a theory: (1) consistency, (2) precision, (3) parsimony, (4) generality, (5) falsifiability, and (6) progress. Nonetheless, quality is not synonymous with suitability. Rather, quality is a superordinate concept of which suitability is a partial aspect. The Oxford dictionary defines suitability as "the quality of being right or appropriate for a particular purpose [...]" (Oxford Learner's Dictionary). This refers to the first two quality criteria of consistency and precision. Consistency refers to "correspondence to empirical observations in the laboratory and/or the real world" (Gieseler et al., 2019, p. 7). However, precision requires "clearly defined concepts and operationalizations that allow for little stretching" (Gieseler et al., 2019, p. 7). In case these are not fulfilled, an application of the theory should be questioned (cf. Gieseler et al., 2019). Therefore, those two criteria were used to assess the suitability of the two remaining theoretical approaches – process life-cycle theory and stage theory.

To identify articles addressing these criteria, a forward search (Webster & Watson, 2002) was performed based on the works of the theory's leading proponents, e.g., van de Ven and Poole (1995)'s work for process life-cycle theory and Nolan (1973)'s paper for stage theory. The searches were conducted in the databases Web of Science and Google Scholar. We considered only academic literature, i.e., articles published in journals, conference proceedings, or books. Relevant aspects were extracted and assigned to the corresponding criterion, i.e., either consistency or precision. Table VII.3 summarizes the results.

Interestingly, the authors who draw on these theoretical approaches are at least partially aware of these suitability issues. As an example, Chaghooshi et al. (2016, p. 561) stated: "Nolan's stage hypothesis, for instance, stimulated much research that resulted in conflicting findings as regards its empirical validity". Other critical statements can be found in Pöppelbuß et al. (2015) and Niehaves et al. (2014, pp. 100–101), who concluded that "[...] developmental models for BPM should not adopt a pure life cycle perspective (Van de Ven and Poole, 1995), but should also consider environmental aspects and organizational traits".

The various criticisms of the stage theory (see Table VII.3) lead to doubts about its suitability as a foundation for BPMMs. Process life-cycle theory appears to be a more viable basis for BPMMs. However, some of the theory's core statements and assumptions may prompt some fundamental criticisms of BPMMs elaborated in the following section.

	Consistency	Precision
Process life-cycle theory	Studies by various researchers have supported the validity of the theory. In many cases, the theory can be found in combination with other process theories (e.g., Bayne et al., 2021, Ellwood et al., 2022, Kaartemo et al., 2020, Nielsen, 2008).	The theory is characterized as simple but nevertheless provides precise explanations (e.g., Pentland, 1999, Swanson & Holton III, 2001). Scholars refer to the theory and its assumptions as detailed and testable (e.g., Habib, 2008, Weick & Quinn, 1999, Nielsen, 2008).
Stage theory	The validity of the theory has been both confirmed and refuted by many empirical studies (e.g., Benbasat et al., 1984, W. R. King & Teo, 1997). For example, the S-shaped curve has not been supported (e.g., Lucas & Sutton, 1977). Criticisms have been voiced regarding validation studies in terms of their reliability and validity tests of the measurement procedures (e.g., Mahmood & Becker, 1985). The stage theory was adapted based on further empirical evidence by Nolan in subsequent years (e.g., Nolan, 1979).	The theory is sometimes described as comprehensive (e.g., Saarinen, 1989). However, the operationalization of the stage model is not publicly available (e.g., Benbasat et al., 1984, J. L. King & Krämer, 1984). The theory does not adequately define individual terms, such as “technical skills” (e.g., Benbasat et al., 1980), nor does it explicitly describe the measurement of organizational maturity (e.g., Mahmood & Becker, 1985). The theory addresses a fairly complex phenomenon “[...] in a straightforward and clever manner” (J. L. King & Krämer, 1984, p. 474). Researchers have criticized its minimalist approach and described its assumptions as too simplified to be useful (e.g., Gottschalk, 2009, J. L. King & Krämer, 1984).

Table VII.3. Evaluation of the theories’ suitability

VII.5 Drawing Parallels to Highlight the Necessity to Rethink the Theoretical Foundations of BPMMs

After juxtaposing the theories' assumptions and the fundamental criticisms of BPMMs (Sect. VII.5.1), the relevance of this paper is addressed and an outlook is provided (Sect. VII.5.2).

VII.5.1 Can the Fundamental Criticisms of BPMMs Be Traced Back to its Weak Theoretical Foundation?

As already highlighted in the introduction to this paper, some scholars have objected to the models' quality. Accordingly, many BPMMs provide insufficient documentation, which makes their application difficult. Moreover, some strong criticism has questioned the overall usefulness of such models. This refers to their linear, static, absolute nature that reflects a positivist approach to deriving highly accurate prediction models. However, it also oversimplifies reality and gives rise to the problems described in more detail below.

Linear. The central premise of most maturity models is that development proceeds along a predefined, cumulative path, which is well reflected by the numbering of maturity stages (Andersen et al., 2020). However, empirical evidence for the existence of such a pattern is lacking. Instead, it is reasonable to conclude that the proposed path depends on the subjective, individual perception of the model designers. Such a linear path further contradicts the fact that competitive advantages result from uniqueness and heterogeneity (Penrose, 1959). If all companies follow the same homogenous one-size-fits-all concept while relying on widely acknowledged best practices, it must be considered impossible to outperform competitors. In addition, most maturity models neglect the potential existence of multiple equally advantageous paths (W. R. King & Teo, 1997).

Static. Every model is developed at a certain point in time. Consequently, they represent a specific state of knowledge that is locked into the model, while the conditions, i.e., competitors, customers, and technology, are constantly evolving. If the environment changes, the model's units of analysis have to continually reflect those changes. However, most maturity models do not provide for such permanent, constant change. Applying a static model to a continuously dynamic context will, therefore, most likely not lead to satisfactory results.

Absolute. The basic concept of maturity with a predefined desirable end state to reach is absolute (Andersen et al., 2020). However, many goals, such as competitiveness, are relative concepts. They depend on the respective context. For instance, businesses do not have to deliver the highest quality possible to be successful. Instead, they only have to be better than competitors. In addition, traditional overarching organizational goals of increased performance and growth do not know an upper limit. Consequently, the normative final stage of the model must be viewed critically since organizational development is continuous and could never be 'complete' as long as a company operates in the market.

While these criticisms are valid for many BPMMs, they do not apply to all of them. Few approaches successfully counteract the aforementioned issues. For instance, some models prescribe a path for a specific capability (e.g., BPM-CF by Rosemann and de Bruin (2005)) and have been updated (e.g., BPM-CF adjusted by Kerpedzhiev et al. (2020)). Nevertheless, it is still notable that the three points of criticism are largely similar to the shortcomings of the theoretical foundations derived in the previous section. Both process life-cycle theory and stage theory assume linear relationships, are static, and point to an absolute end state. Such assumptions, however, do not adequately reflect reality. Figuratively speaking, it seems as if the foundation on which the maturity models are based is weak and unstable. As a result of the abductive reasoning process, we, therefore, hypothesize that the highlighted theoretical shortcomings most likely cause some of the BPMMs' fundamental weaknesses. Therefore, it appears not only promising but also necessary to return to the roots, rethink the theoretical basis of maturity models, and look for more suitable alternatives.

VII.5.2 What Is the Relevance of This Research and What Are Possible Next Steps Moving Forward?

Compared to other streams of BPMM research, epistemological studies have received comparatively little attention despite their relevance to the longevity of maturity models. The previously published articles by Niehaves et al. (2013), Niehaves et al. (2014), and Pöppelbuß et al. (2015) used case study data to highlight that the theories underlying maturity models do not correspond to the development of organizational capabilities. More than five years have passed since publication. The paper at hand reinforces the results of the previously published article, yet the findings also imply that the few previous contributions have not led to reconsideration in the maturity model domain. BPMMs published in recent years continue to have no or inadequate theoretical foundations. Regardless of such omissions, a strong foundation improves the explanatory power of such artifacts and supports the causal effects of BPM maturity on business performance. Moreover, the lack of theoretical grounding is not limited to BPMMs but also applies to maturity models in general (e.g., Bvuchete et al., 2018, Patas, 2015, Thordsen et al., 2020). Lasrado et al. (2016, p. 5) noted that some model designers do "[...] not conceptually grounding the maturity model characteristics in theory". In addition, they questioned whether those procedure models are adequately supported by theory and provided a new perspective. They suggested set-theoretic methods such as the qualitative comparative analysis (QCA) and the necessary condition analysis (NCA) to conceptualize maturity stages and stage configuration. The novel analytic approach is a counterposition to generic, absolute designs and takes a relative perspective on each case, which reduces the arbitrariness in the model structure. Furthermore, it overcomes the linear structure of BPMMs by allowing for multiple paths toward maturity. Bley (2021) showed the approach's applicability, which can be understood as the first step of a paradigm shift. This paper complements their effort for the advancement of maturity models and shows that the increasing complexity of reality requires a refinement of the models' theoretical foundation. Such necessity raises numerous elementary questions about the future of BPMMs, three of which are broached in the following.

First, the set-theoretic approach changes the way maturity levels are derived. Nevertheless, it remains to be seen to what extent maturity levels make any sense at all. Higher maturity levels are not always automatically better, the existence of a single linear path is questionable, and the capabilities associated with a maturity level are constantly changing (Dijkman et al., 2015; Niehaves et al., 2014; Pöppelbuß et al., 2015). A viable alternative might be to consider maturity gaps instead of maturity levels. These maturity gaps arise from the market and customer-specific requirements for processes on the one hand and the status quo on the other.

Second, maturity models lack a time dimension that does justice to dynamic changes. Because of this, developed models are actually already outdated at the time of publication. Furthermore, so-called best practices from today may already be obsolete tomorrow. To account for continuous change, the models would need to have a circular, self-perpetuating component that gives them an evolutionary capability and ensures that the maturity itself can mature.

Third, the current consensus is that models should be descriptive, prescriptive, and comparative. The prescriptive component, i.e., guidance on how to follow the proposed development path, is even emphasized by many authors or criticized if it is missing (Pöppelbuß & Röglinger, 2011; Tarhan et al., 2016). However, can there be a satisfactory prescriptive model component when competitive advantage cannot be derived from widely used best practices, and most effective and efficient solutions depend on the individual case? Perhaps it must be admitted that the prescriptive purpose, while desirable, is beyond what a maturity model can accomplish.

To conclude, this section, we provide a brief outlook. First, the results obtained should be validated by considering other domains. Currently, anecdotal evidence indicates that the phenomenon under investigation can also be identified in other domains (e.g., Bvuchete et al., 2018, Patas, 2015, Thordsen et al., 2020). Accordingly, it may be advantageous not to recommend theories as suitable for one specific domain but to address this issue for maturity models in general. Second, the requirements of the models should be defined to propose suitable theories that can guide their development. There seem to be theories with the potential to meet the requirements better and simplify reality less, such as structural contingency theory (Donaldson, 2001; Lawrence & Lorsch, 1967), diffusion of innovation theory (Rogers, 1962), dynamic capability theory (Teece et al., 1997), and evolutionary theory (Dosi & Nelson, 1994; Nelson & Winter, 1982). The latter seems particularly suitable since it "[...] helps uncover processes through which change happens as well as untangle key relationships among the key factors (e.g., internal, environmental, technological) that affect processes" (Vaast & Binz-Scharf, 2008, p. 2). The answer to the obvious question of which theoretical foundation is best suited goes beyond the purpose of this paper and needs to be answered in a dedicated future effort. It is possible that a combination in the sense of a theoretical multiplicity is most feasible (Park et al., 2020).

VII.6 Conclusion

This conceptual work analyzed the literature to show that existing BPMMs in particular and maturity models in general often lack a theoretical foundation. In other words, many researchers blindly adopt the structure of popular existing models without theoretically justifying the fundamental model properties and mechanisms. Moreover, the few theories used need to be critically reflected upon. There are striking analogies between the suitability issues of the theoretical approaches on which previous research has relied and the shortcomings of BPMMs. Abductive reasoning highlighted that a different theoretical foundation appears to be necessary, one that provides a more stable bedrock for developing these models. Economic realities are nonlinear, dynamic, and relative because they depend on the context of the particular object of study. The concept of maturity should therefore reflect this.

A limitation of the paper is that only the 25 BPMMs identified by Tarhan et al. (2016) and Felch and Asdecker (2020) were analyzed. Despite the limited number of models examined, the results are conclusive considering the lack of theoretical foundation. Furthermore, the literature review for potential theories was limited to BPMM articles. Indications suggest that other domains likewise suffer from a similarly weak theoretical foundation of maturity models. The approach described in the article can be adopted for different domains. Two theories were assessed for their suitability. Although a comprehensive literature review was conducted, Table VII.3 does not represent an exhaustive list of agreements and criticisms for each theory. Rather, it highlights frequently mentioned, relevant aspects.

Despite the aforementioned limitations, this paper provides several important contributions: First, it raises and reinforces theoretical concerns. Continued critical reflection on the broader theoretical antecedents of BPMMs is essential to avoid “reinventing the wheel” and instead encourage innovative disruption. Second, this research raises elementary questions about the future of BPMMs, which can serve as the fruitful basis of a research agenda for a so far rarely considered literature stream. Third, the article at hand also contributes to the question of how to potentially improve the identified issues. Whether this is a matter of selected separate aspects of maturity models (e.g., a more dynamic model environment with frequent updates) or an actual paradigm shift in the development process remains to be seen and must be the result of future research.

VII.7 Supplementary Material A. Overview of the 25 Released BPMMs

The table contains 25 business process maturity models (BPMMs) that were classified as 'released' according to Tarhan et al. (2016) and Felch and Asdecker (2020) and published between 1990 and 2019. The numbers listed in the first column as well as the references of the BPMMs were adopted from the article by Tarhan et al. (2016) and Felch and Asdecker (2020).

No	Reference of BPMM publications (1990–2014)
S3	Cronemyr, P., & Danielsson, M. (2013). Process Management 1-2-3 – A Maturity Model and Diagnostics Tool. *Total Quality Management & Business Excellence, 24*(7–8), 933–944.
S7	de Bruin, T., & Rosemann, M. (2007). Using the Delphi Technique to Identify BPM Capability Areas. In *Proceedings of the 18th Australasian Conference on Information Systems,* Toowoomba, Australia.
S12	Hammer, M. (2007). The Process Audit. *Harvard Business Review, April,* 1–14.
S13	Heinze, P., & Geers, D. (2009). Quality Management in Knowledge Intensive Business Processes – Development of a Maturity Model to Measure the Quality of Knowledge Intensive Business Processes in Small and Medium Enterprises. In *Proceedings of the 1st International Conference on Knowledge Management and Information Sharing,* Funchal, Portugal.
S14	Jadhav, M., & Sapre, G. (2009). The Business Process Maturity Model – A Tool to Assess Capability of Business Process. In *Proceedings of the 11th International Conference on Informatics and Semiotics in Organisations,* Beijing, China.
S16	Jochem, R., Geers, D., & Heinze, P. (2011). Maturity Measurement of Knowledge-intensive Business Processes. *TQM Journal, 23*(4), 377–387.
S17	Kangilaski, T., Polyantchikov, I., & Shevtshenko, E. (2013). Partner Network and its Process Management. In *Proceedings of the 10th International Conference on Informatics in Control, Automation and Robotics,* Reykjavík, Iceland.

No	Reference of BPMM publications (1990–2014)
S20	Lee, J [Jihyun], Lee, D., & Kang, S. (2007). An Overview of the Business Process Maturity Model (BPMM). In K. C.-C. Chang, W. Wang, L. Chen, C. A. Ellis, C.-H. Hsu, A. C. Tsoi, & H. Wang (Eds.), *Lecture Notes in Computer Science: Vol. 4537, Advances in Web and Network Technologies, and Information Management* (pp. 384–395). Springer.
S22	Moradi-Moghadam, M., Safari, H., & Maleki, M. (2013). A Novel Model for Business Process Maturity Assessment through Combining Maturity Models with EFQM and ISO 9004:2009. *International Journal of Business Process Integration and Management, 6*(2), 167–184.
S25	Paunescu, C. (2009). Business Maturity Assessment Model: A Practical Approach for Identifying Opportunities for Sustainability Improvement. In *Proceedings of the Annals of DAAAM and Proceedings of the 20th International DAAAM Symposium,* Vienna, Austria.
S31	Rohloff, M. (2009a). An Approach to Assess the Implementation of Business Process Management in Enterprises. In *Proceedings of the 17th European Conference on Information Systems,* Verona, Italy.
S32	Rohloff, M. (2010). Advances in Business Process Management Implementation based on a Maturity Assessment and Best Practice Exchange. *Information Systems and E-Business Management, 9*(3), 383–403.
S33	Rohloff, M. (2009b). Case Study and Maturity Model for Business Process Management Implementation. In U. Dayal, J. Eder, J. Koehler, & H. A. Reijers (Eds.), *Lecture Notes in Computer Science: Vol. 5701, Business Process Management* (pp. 128–142). Springer.
S34	Rohloff, M. (2009c). Process Management Maturity Assessment. In *Proceedings of the 15th Americas Conference on Information Systems,* San Francisco, United States of America.
S36	Rosemann, M., de Bruin, T., & Hueffner, T. (2004). A Model for Business Process Management Maturity. In *Proceedings of the 10th Americas Conference on Information Systems,* New York, United States of America.
S37	Rosemann, M., & de Bruin, T. (2005). Towards a Business Process Management Maturity Model. In *Proceedings of the 13th European Conference on Information Systems,* Regensburg, Germany.
S38	Saco, R. M. (2008). Maturity Models: Inject New Life. *Industrial Management, 50*(4), 11–15.

No	Reference of BPMM publications (1990–2014)
S40	Škrinjar, R., Dimovski, V., Škerlavaj, M., & Indihar-Štemberger, M. (2006). Process Maturity and Organizational Structure as a Framework for Performance Improvements. In A. G. Nilsson, R. Gustas, W. Wojtkowski, S. Wrycza, & J. Zupančič (Eds.), *Advances in Information Systems Development* (pp. 95–106). Springer.
S59	Willaert, P., van den Bergh, J., Willems, J., & Deschoolmeester, D. (2007). The Process-Oriented Organisation: A Holistic View Developing a Framework for Business Process Orientation Maturity. In G. Alonso, P. Dadam, & M. Rosemann (Eds.), *Lecture Notes in Computer Science, Business Process Management* (pp. 1–15). Springer.
S61	Zwicker, J., Fettke, P., & Loos, P. (2010). Business Process Maturity in Public Administrations. In J. vom Brocke & M. Rosemann (Eds.), *Handbook on Business Process Management 2: Strategic Alignment, Governance, People and Culture* (pp. 485–512). Springer.

No	Reference of BPMM publication (2015–2019)
A2	Andriani, M., Samadhi, T. A., Siswanto, J., & Suryadi, K. (2018). Aligning Business Process Maturity Level with SMEs Growth in Indonesian Fashion Industry. *International Journal of Organizational Analysis, 26*(4), 709–727.
A4	Chaghooshi, A. J., Moradi-Moghadam, M., & Etezadi, S. (2016). Ranking Business Processes Maturity by Modified Rembrandt Technique with Considering CMMI Dimensions. *Iranian Journal of Management Studies, 9*(3), 559–578.
A11	Froger, M., Bénaben, F., Truptil, S., & Boissel-Dallier, N. (2019). A Non-linear Business Process Management Maturity Framework to Apprehend Future Challenges. *International Journal of Information Management, 49*, 290–300.
A34	Sliż, P. (2018). Concept of the Organization Process Maturity Assessment. *Journal of Economics and Management, 33*(3), 80–95.
A50	Berger, R., Wellbrock, W., Aksoy, O., & Mulzer, D. (2018). Process Orientation: An Approach to Optimize Cross-company Supply Chains - Insights from a Descriptive Study. In *Proceedings of the 30th Annual NOFOMA Conference,* Kolding, Denmark.

VII.8 Supplementary Material B. Overview of the Topics Addressed Prior to BPMM Design

Abbreviation of BPMM publication (1990–2019)	Definition of maturity (model)	Description/comparison of models	History of models	Purpose of models	Shortcomings of models	Theories mentioned	No reference to models
Cronemyr and Danielsson [S3]		●		●			
de Bruin and Rosemann [S7]		●		●	●		
Hammer [S12]							●
Heinze and Geers [S13]	●						
Jadhav and Sapre [S14]	●	●					
Jochem et al. [S16]	●			●			
Kangilaski et al. [S17]							●
Lee et al. [S20]	●	●		●	●		
Moradi-Moghadam et al. [S22]	●	●	●	●	●		
Paunescu [S25]		●		●	●		
Rohloff [S32]		●	●				
Rosemann et al. [S36]	●	●	●		●		
Rosemann and de Bruin [S37]	●	●	●		●		
Saco [S38]				●			

Abbreviation of BPMM publication (1990–2019)	Definition of maturity (model)	Description/comparison of models	History of models	Purpose of models	Shortcomings of models	Theories mentioned	No reference to models
Skrinjar et al. [S40]		●					
Willaert et al. [S59]		●					
Zwicker et al. [S61]	●	●		●	●		
Andriani et al. [A2]		●					
Chaghooshi et al. [A4]		●	●	●		●	
Froger et al. [A11]	●	●		●			
Sliż [A34]	●	●					
Berger et al. [A50]				●			

VII.9 Supplementary Material C. Complete List of the 49 Articles Included in the Literature Search

The table provides an overview of all 49 articles analyzed with regard to the theoretical foundation of BPMMs.

No	Reference of the article
1	Ahmed, F., & Capretz, L. F. (2010). An Organizational Maturity Model of Software Product Line Engineering. *Software Quality Journal, 18*(2), 195–225.
2	Barafort, B., Mesquida, A.-L., & Mas, A. (2017). Developing an Integrated Risk Management Process Model for IT Settings in an ISO Multi-standards Context. In A. Mas, A.-L. Mesquida, R. V. O'Connor, T. Rout, & A. Dorling (Eds.), *Communications in Computer and Information Science, Software Process Improvement and Capability Determination* (pp. 322–336). Springer.
3	Barafort, B., Mesquida, A.-L., & Mas, A. (2018). Integrated Risk Management Process Assessment Model for IT Organizations based on ISO 31000 in an ISO Multi-standards Context. *Computer Standards & Interfaces, 60,* 57–66.
4	Carcary, M., & Zlydareva, O. (2014). Investigating the Application of the IT-CMF in Maturing Strategic Business-IT Alignment. In *Proceedings of the 8th European Conference on IS Management and Evaluation,* Ghent, Belgium.
5	Colin-Lozano, H. D., Guerra-Loji, S., Vargas-Alvarado, M. A., Valdez-de la Rosa, Luz Maria, & Vázquez-Hernández, J. (2019). Lean Manufacturing Maturity Model for an Automotive Cluster: A Case Study in Mexico. In *Proceedings of the 4th North American IEOM Conference,* Toronto, Canada.
6	Curley, M. (2008). Introducing an IT Capability Maturity Framework. In J. Filipe, J. Cordeiro, & J. Cardoso (Eds.), *Lecture Notes in Business Information Processing: Vol. 12, Enterprise Information Systems* (pp. 63–78). Springer.
7	da Rosa, I., & da Silva, M. M. (2015). A Maturity Model for Business Transformation Management. In *Proceedings of the 17th Conference on Business Informatics,* Lisbon, Portugal.

No	Reference of the article
8	de Meirelles Quintella, H. L., & Farias de Toledo, R. (2017). How Quality Perceived by the Client Connect with Cmm Maturity and Quality of Six Sigma Processes. *Business Management Dynamics*, *6*(11), 1–15.
9	Felch, V., & Asdecker, B. (2020). How to Make Business Process Maturity Models Better – Drawing on Design Science Research. In *Proceedings of the 24th Pacific Asia Conference on Information Systems,* virtual.
10	García Aranda, J. R., & García Márquez, F. P. (2015). Use of Excellence Models as a Management Maturity Model (3M). In F. P. García Márquez & B. Lev (Eds.), *Advanced Business Analytics* (pp. 165–179). Springer.
11	Hovmøller Mortensen, M., Vagn Freytag, P., & Stentoft Arlbjørn, J. (2008). Attractiveness in Supply Chains: A Process and Matureness Perspective. *International Journal of Physical Distribution & Logistics Management, 38*(10), 799–815.
12	Howard, J., & Gillies, A. (2009). Knowledge to Innovate: Developing a Tool to Assess and Assist the Development of the Capacity to Innovate in Small and Medium Sized Enterprises. In *Proceedings of the 4th European Conference on Entrepreneurship and Innovation,* Antwerp, Belgium.
13	Jensen, P. M., Johansen, J., Waehrens, B. V., & Shewan-Ul-Alam, M. (2013). Proposing an Environmental Excellence Self-Assessment Model. In C. Emmanouilidis, M. Taisch, & D. Kiritsis (Eds.), *IFIP Advances in Information and Communication Technology: Vol. 398, Advances in Production Management Systems. Competitive Manufacturing for Innovative Products and Services* (pp. 511–518). Springer.
14	Li, H., & Gong, W. (2011). The Model and Evaluation Research of Business Integration Maturity in Financial Holding Company. In *Proceedings of the International Conference on Strategic Management,* Phuket, Thailand.
15	Marcineková, K., & Sujová, A. (2015). The Influence of the Process Control Level on the Enterprises' ROE. *Procedia Economics and Finance, 34,* 290–295.
16	Márcio Tavares Thomé, A., Luis Hollmann, R., & Scavarda, L. F. (2014). Research Synthesis in Collaborative Planning Forecast and Replenishment. *Industrial Management & Data Systems, 114*(6), 949–965.
17	Mathiesen, P., Bandara, W., & Watson, J. (2013). The Affordances of Social Technology: A BPM Perspective. In *Proceedings of the 34th International Conference on Information Systems,* Milan, Italy.

No	Reference of the article
18	Niehaves, B., Plattfaut, R., & Becker, J. (2013). Business Process Management Capabilities in Local Governments: A Multi-method Study. *Government Information Quarterly*, *30*(3), 217–225.
19	Niehaves, B., Pöppelbuß, J., Plattfaut, R., & Becker, J. (2014). BPM Capability Development – A Matter of Contingencies. *Business Process Management Journal*, *20*(1), 90–106.
20	Opitz, N., Krüp, H., & Kolbe, L. M. (2014). Environmentally Sustainable Business Process Management – Developing a Green BPM Readiness Model. In *Proceedings of the 18th Pacific Asia Conference on Information Systems,* Chengdu, China.
21	Panda, S., & Rath, S. K. (2018). Strategic IT-business Alignment and Organizational Agility: From a Developing Country Perspective. *Journal of Asia Business Studies*, *12*(4), 422–440.
22	Pidun, T., & Felden, C. (2010). An Overview of Models for Business Process Analysis – Beyond Performance Measurement with KPIs. In *Proceedings of the 14th International Enterprise Distributed Object Computing Conference Workshops,* Vitoria, Brazil.
23	Pöppelbuß, J., Plattfaut, R., & Niehaves, B. (2015). How Do We Progress? An Exploration of Alternate Explanations for BPM Capability Development. *Communications of the Association for Information Systems, 36*, 1–22.
24	Proença, D., & Borbinha, J. (2018). Using Enterprise Architecture Model Analysis and Description Logics for Maturity Assessment. In H. M. Haddad, R. L. Wainwright, & R. Chbeir (Eds.), *Symposium on Applied Computing* (pp. 102–109). Association for Computing Machinery.
25	Pulparambil, S., Baghdadi, Y., & Salinesi, C. (2021). A Methodical Framework for Service Oriented Architecture Adoption: Guidelines, Building Blocks, and Method Fragments. *Information and Software Technology, 132.*
26	Ravesteijn, P., Smit, J., & McGuinness, B. (2016). A Study on the Relation between Business Process Management Maturity and Innovation. In *Proceedings of the 22nd Americas Conference on Information Systems,* San Diego, United States of America.

No	Reference of the article
27	Röglinger, M., Schwindenhammer, L., & Stelzl, K. (2018). How to Put Organizational Ambidexterity into Practice – Towards a Maturity Model. In M. Weske, M. Montali, I. Weber, & J. vom Brocke (Eds.), *Lecture Notes in Business Information Processing: Vol. 329, Business Process Management Forum* (pp. 194–210). Springer.
28	Rong, G., Zhang, H., & Shao, D. (2016). CMMI Guided Process Improvement for DevOps Projects. In D. E. Perry & D. Raffo (Eds.), *International Conference on Software Engineering* (pp. 76–85). Association for Computing Machinery.
29	Roorda, D., & Liu, M. K. (2008). Implementation of Building Information Modeling (BIM) on the Renovation of the Art Gallery of Alberta in Edmonton, Alberta. In M. A. Bhatti, C. M. Foley, & F. A. Charney (Eds.), *Analysis and Computation Specialty Conference at Structures Congress* (pp. 1–15). American Society of Civil Engineers.
30	Sehlin, D., Truedsson, M., & Cronemyr, P. (2019). A Conceptual Cooperative Model Designed for Processes, Digitalisation and Innovation. *International Journal of Quality and Service Sciences, 11*(4), 504–522.
31	Sincorá, L. A., de Oliveira, M. P. V., Zanquetto-Filho, H., & Ladeira, M. B. (2018). Business Analytics Leveraging Resilience in Organizational Processes. *RAUSP Management Journal, 53*(3), 385–403.
32	Singh Srai, J., & Gregory, M. (2008). A Supply Network Configuration Perspective on International Supply Chain Development. *International Journal of Operations & Production Management, 28*(5), 386–411.
33	Spruit, M., & Sacu, C. (2015). DWCMM: The Data Warehouse Capability Maturity Model. *Journal of Universal Computer Science, 21*(11), 1508–1534.
34	Stevens, S. (2006). Applying CMMI and Strategy to ATE Development. In *Proceedings of the Autotestcon,* Anaheim, United States of America.
35	Szelagowski, M., & Berniak-Woźny, J. (2020). The Adaptation of Business Process Management Maturity Models to the Context of the Knowledge Economy. *Business Process Management Journal, 26*(1), 212–238.
36	Tapia, R. S., Daneva, M., van Eck, P., & Wieringa, R. (2008). Towards a Business-IT Aligned Maturity Model for Collaborative Networked Organizations. In *Proceedings of the 12th Enterprise Distributed Object Computing Conference Workshops,* Munich, Germany.

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37	Utami, W., Khrisnabudi, N. G., Farida, L., Apriono, M., Utami, E. S., Sudarsih, Gumanti, T. A., & Wulandari, D. R. (2020). Measurement of Maturity of Small Medium Agroindustry Business Processes in Jember, Indonesia. *Journal of Physics: Conference Series, 1538,* 1–11.
38	van Beelaerts Blokland, W., van de Koppel, S., Lodewijks, G., & Breen, W. (2019). Method for Performance Measurement of Car Companies from a Stability-Value Leverage Perspective. *International Journal of Lean Six Sigma, 10*(1), 411–434.
39	van den Bergh, J., & Viaene, S. (2012). The Growth Path towards the Process-Oriented Organisation. In *Proceedings of the 18th International Business Information Management Association Conference,* Istanbul, Turkey.
40	van Looy, A. (2020). Capabilities for Managing Business Processes: A Measurement Instrument. *Business Process Management Journal, 26*(1), 287–311.
41	van Looy, A., de Backer, M., & Poels, G. (2010). Which Maturity Is Being Measured? A Classification of Business Process Maturity Models. In *Proceedings of the 5th SIKS/BENAIS Conference on Enterprise Information Systems,* Eindhoven, The Netherlands.
42	van Looy, A., de Backer, M., & Poels, G. (2014). A Conceptual Framework and Classification of Capability Areas for Business Process Maturity. *Enterprise Information Systems, 8*(2), 188–224.
43	van Looy, A., de Backer, M., & Poels, G. (2011). Defining Business Process Maturity. A Journey towards Excellence. *Total Quality Management & Business Excellence, 22*(11), 1119–1137.
44	van Looy, A., de Backer, M., Poels, G., & Snoeck, M. (2013). Choosing the Right Business Process Maturity Model. *Information & Management, 50*(7), 466–488.
45	von Känel, J., Cope, E. W., Deleris, L. A., Nayak, N., & Torok, R. G. (2010). Three Key Enablers to Successful Enterprise Risk Management. *IBM Journal of Research and Development, 54*(3), 1:1-1:15.
46	Vukšić, V. B., Bach, M. P., Grubljesic, T., Jaklic, J., & Stjepić, A.-M. (2017). The Role of Alignment for the Impact of Business Intelligence Maturity on Business Process Performance in Croatian and Slovenian Companies. In *Proceedings of the 40th International Convention on Information and Communication Technology, Electronics and Microelectronics,* Opatija, Croatia.

No	Reference of the article
47	Welo, T., & Ringen, G. (2018). Investigating Organizational Knowledge Transformation Capabilities in Integrated Manufacturing and Product Development Companies. *Procedia CIRP*, *70*, 150–155.
48	Widmann, V., de Waal, B. M. E., & Ravesteijn, P. (2018). How Do BPM Maturity and Innovation Relate in Large Companies? In Á. Rocha, H. Adeli, L. P. Reis, & S. Costanzo (Eds.), *Advances in Intelligent Systems and Computing: Vol. 747, Trends and Advances in Information Systems and Technologies* (pp. 87–96). Springer.
49	Yin, Y. (2016). Study on the Evaluation of Business Process Management Maturity Based on Sustainable Development. In *Proceedings of the 12th Euro-Asia Conference on Environment and CSR,* Hanover, Germany.

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Various developments, such as economic uncertainties, growing market dynamics, or unexpected events, e.g., the COVID-19 pandemic, affect organizations and their business processes. To remain competitive and ensure long term survival, organizational capabilities and processes need to be continuously adapted. Numerous (business process) maturity models have been released as guidance for organizations, which can assist in determining the current state, highlighting improvement measures, and enabling cross-organizational comparisons.

Although the ascribed potential seems high, this dissertation takes a critical perspective by (1) highlighting prevailing points of criticism of models that are inherent in the design and publication process, (2) verifying the anecdotal evidence of these issues, (3) identifying reasons for the points of criticism, and (4) suggesting the framework REMMAP to enhance upcoming model designs and improve released maturity models.

The dissertation contributes to the existing body of knowledge by (1) drawing the attention of model designers to prevailing points of criticism to improve the design and publication of released and future models, (2) assisting reviewers and editors in thoroughly screening submitted works, and (3) supporting users in selecting appropriate models as well as providing them with more substantiated and transparent models in the future.