POTENTIAL MODEL - METHODICAL EVALUATION OF INDUSTRY 4.0 TECHNOLOGIES

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ABSTRACT

With regard to the currently perceptible technological, social and economic change, also known as the "Fourth Industrial Revolution" or "Internet of Things", small and medium-sized enterprises (SMEs) in particular are confronted with various obstacles in their attempt of keeping pace. For example, there is a lack of orientation of which I4.0 technology is suitable for a target-oriented application. Furthermore, the actual or potential effects of I4.0 can only be estimated insufficiently and SMEs are at a disadvantage compared to large companies due to lower monetary and personnel capacities. In this publication these obstacles on the way to become an I4.0 company are taken up and the core elements of a methodical solution approach in the form of the "Potential Model" are explained in detail. Thereby the Potential Model is intended to support SMES at the rough-quantitative evaluation of I4.0 and the development of I4.0 implementation strategies with minimal monetary and time-related efforts needed.

Keywords: Industry 4.0, Technology, Evaluation, Design methods

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1 INTRODUCTION

Since its initiation at the Hanover Fair 2011 (Matt et al., 2020; Roth, 2016; Sendler, 2016), the "Industry 4.0" strategy has been keeping the global economy and research intensively occupied. Over the past decade, numerous and diverse projects have been carried out in the field of Industry 4.0 in order to fully exploit the potential and possibilities of technological change. (Schneider et al., 2020) In the following, the current status and focus of research in the field of Industry 4.0 (I4.0) is described and the industrial needs and obstacles for the strategic implementation of I4.0 technologies are highlighted. In this publication, the term "Industry 4.0" unites the development and implementation of innovative technologies that support companies in facing the advancing technological, economic and social change. In this publication the term "Industry 4.0" also describes all methodological tools that support companies in the implementation of the innovative technologies mentioned.

1.1 State and focus of research

The support of industrial companies in the strategic and practical realisation of the fourth industrial revolution can be recorded as a general goal of the worldwide extensive research activities on I4.0. (Pereira and Romero, 2017; Schneider et al., 2020; Wichmann et al., 2019) In order to better determine the state of research in the field of Industry 4.0, a systematic literature search was conducted and combined with a comparative analysis. Research projects and results from reputable German research institutions were investigated. Finally, 30 research projects from different research institutions were selected that are representative of the state of research on I4.0 - at least in Germany. As a result of the literature research and the comparative analysis of the 30 identified, representative I4.0 research projects, three focal points of method-focused research on I4.0 emerged. (Schneider, 2021) As *Maturity analyses* those projects were categorised, that support companies in assessing their current state under aspects of Industry 4.0. *Technology assessment* methods, on the other hand, support the assessment of the suitability as well as the impact of various I4.0 technologies. Each methodological tool that supports the development of implementation strategies for I4.0 was assigned to the *roadmap development*. In the course of the comparative analysis, observations from previous, independent literature research were confirmed - for example, that the general focus of research in the field of Industry 4.0 is on production as the central phase of product generation (Abramovici et al., 2018; Schuh et al., 2017; Terstegen et al., 2019). It could also be confirmed that, despite the high relevance of product development, which is based on its strong interdisciplinarity and the manifold interactions with upstream and downstream phases of product generation (Lindemann, 2016; Vajna, 2014), little attention is paid to it in I4.0 research. Furthermore, it was possible to confirm the previous observation that many of the currently existing methods lack of customisability and often only operate at superordinate levels at which no specific reference is made to individual I4.0 technologies.

1.2 Obstacles of the I4.0 technology implementation

With regard to the focus of the research, which includes the development of new methods to support a strategic and expedient implementation of I4.0 technologies, the obstacles that delay and hinder the widespread industrial revolution are addressed in particular. Especially small and medium-sized enterprises (SMEs) are confronted with these obstacles, which encounter in form of insufficient predictability of the effects of individual I4.0 technologies in conjunction with high initial investments or increasing overall system complexity through the use of I4.0 as well as insufficiently fulfilled basic infrastructural prerequisites. (Andelfinger and Hänisch, 2017; Erol et al., 2016; Matt et al., 2020; Schröder, 2016; Wichmann et al., 2019) In contrast to large companies, SMEs are at a particular disadvantage in this regard due to lower liquidity as well as lower resource availability for assessing the impact of individual I4.0 technologies. (Faller and Feldmüller, 2015; Koch et al., 2014; Schneider et al., 2020)

1.3 Potential Model as a solution approach

The Potential Model, presented as a solution approach by Schneider et al. (2020), addresses the deficits of current research in the field of Industry 4.0, mentioned in **Chapter 1.1,** as well as the barriers of SMEs in the implementation and evaluation of I4.0 technologies, mentioned in **Chapter 1.2**. The objective of the Potential Model is to support SMEs in the selection of suitable I4.0 technologies depending on their current status evaluated under aspects of I4.0 and their individual

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strategic priorities. In the course of the application of the Potential Model, the actual state of a company is first determined with the help of "evaluation criteria", followed by the identification of potentials for the targeted use of individual I4.0 technologies. This is supplemented by a rough quantitative impact prognosis, which determines a technology-dependent target state for the actual state of the company. The method is intended to provide a cross-phase view of product generation with a special focus on product development. Furthermore, it is intended to provide a high degree of usability and individualisation of the results, which will enable SMEs in particular to develop I4.0 implementation strategies with minimal monetary and time expenditure. (Schneider et al., 2020)

2 OBJECTIVE AND FOCUS OF THIS PUBLICATION

The scientific contribution of this publication is a detailed description of all elements and the inherent interdependencies of the Potential Model (PM). One focus of this publication is on the evaluation criteria used to evaluate the current state of a company with regard to I4.0 (maturity level) and to assess the suitability of various I4.0 technologies. Furthermore, the evaluation scale as well as the underlying calculation and evaluation scheme of the PM is described in detail. The development and provision of the I4.0 technology catalogue, which forms an important basis of the PM at the functional level, is also addressed in this publication. The functional description of the PM and its conceptual presentation by Schneider et al. (2020) is roughly taken up in this publication and serves as a starting point for the detailing of the central components of the PM. In summary, the outcome of this publication is the presentation of a novel assessment scheme for I4.0 technologies that addresses the methodical research focus on maturity analysis and technology assessment (**Chapter 1.1**) as well as the barriers SMEs face in adopting I4.0 (**Chapter 1.2**) and links I4.0 technologies to specific I4.0 evaluation criteria. It is *not* the purpose of this paper to describe the basic functionality and the advantages of the Potential Model *in detail*, for which reference is made to the publication of Schneider et al (2020).

This publication is intended to answer the research questions listed below:

- Which criteria are the basis of the implementation of I4.0 technologies from the perspective of industry and science and can be used for technology assessment?
- Which superior technological solution concepts of I4.0 can be identified and used for the development of implementation strategies?
- How are evaluation criteria and I4.0 technologies linked in the course of recording an individual current state of a company and recommending one or more suitable technologies?

In order to answer these questions, **Chapter 3** first explains the most important fundamentals of the Potential Model, with reference to its basic functionality and structure. This is followed by a detailed description of the evaluation criteria and the I4.0 technology catalogue, which represent the essential components of the Potential Model. Thereupon the linkage of the catalogue and the evaluation criteria is further explained, whereby reference is made to the underlying evaluation scheme. In **Chapter 4** the application of the Potential Model is brought up for discussion, whereby two application variants and scenarios are presented. The publication concludes with a summary of the main contents of this paper and an outlook on further research in **Chapter 5**.

3 METHODICAL POTENTIAL EVALUATION OF I4.0 TECHNOLOGIES

The Potential Model (PM) is designed for the methodical support of the strategic selection of I4.0 technologies and the targeted initiation of measures that enable a company to become I4.0 (**Chapter 1**). The PM does *not* aim at supporting the technical implementation of an I4.0 technology and furthermore does *not* generate highly precise quantitative and process-specific values for I4.0-related impact prognosis. In this chapter, first the basic function of the PM is explained with regard to the publication of Schneider et al. (2020). After this, the I4.0 technology catalogue and the I4.0 evaluation criteria are described in detail as central elements of the PM.

3.1 Basic structural and functional knowledge about the Potential Model

In **Figure 1**, the central components of the PM are shown. First, there are *evaluation criteria*, which are subdivided into four superordinate *company perspectives* and used to assess the current state of the company and the suitability of I4.0 technologies. Furthermore, there is the *I4.0 technology catalogue*,

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which contains a collection of I4.0 technologies and describes them in detail. It also contains information of the potential impact of individual technologies on the PM evaluation criteria and thus is a basis for the linking of evaluation criteria and specific I4.0 technologies as mentioned in **Chapter 2**. The interface between evaluation criteria and I4.0 catalogue is the evaluation scale, which thus enables the evaluation of I4.0 technologies. Using the evaluation criteria of the PM, company-specific data is collected based on the user's input. These inputs are highly individual and form the basis for the individualisation and adaptability of the PM results. In contrast, the technology catalogue provides static knowledge on I4.0 technologies. Both, the user-specified input, which takes place via the evaluation criteria, as well as the static knowledge of the I4.0 catalogue are documented using the evaluation scale, which thus forms the basis for the application of the PM.

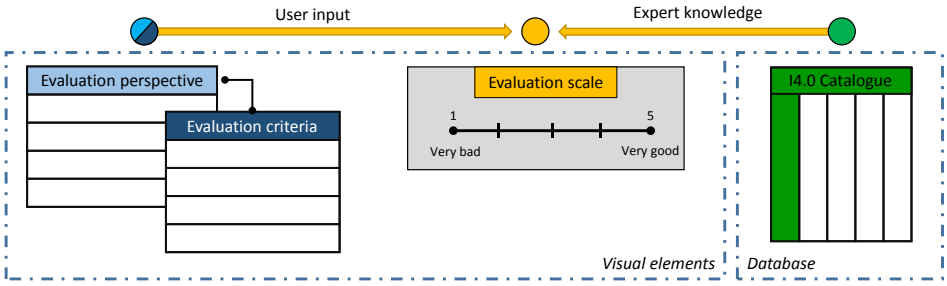

Figure 1. Main elements of the Potential Model

The main elements of the PM are shown in **Figure 1** and explained in more detail in **Chapter 3.2**. In **Figure 2**, the sequential PM application is illustrated and the main elements of **Figure 1** are assigned to the individual application steps. In step 1, first the actual state of a company is recorded. In this process, the user estimates the actual company state on an endpoint defined evaluation scale in relation to each evaluation criterion. For the purpose of clarity and comprehensibility, the criteria are assigned to four evaluation perspectives. Based on the user's assessment, the implementation potential of I4.0 technologies are identified in step 2. The evaluation criteria whose current status was indicated as insufficient are the indicators for the I4.0 implementation potential. Subsequently, in step 3, the suitability of the technologies listed in the I4.0 catalogue is evaluated in relation to the current state of the company. In this process, the static catalogue data in the form of potential effects of the I4.0 technologies on the individual evaluation criteria is used. The suitability of the I4.0 technologies is evaluated in detail with the usual marks from "excellent" to "unsatisfactory" by offsetting the actual state of the evaluation criteria against their potential I4.0 state from the I4.0 catalogue. Finally, step 4 of the PM application is followed by the (graphical) visualisation of the result.

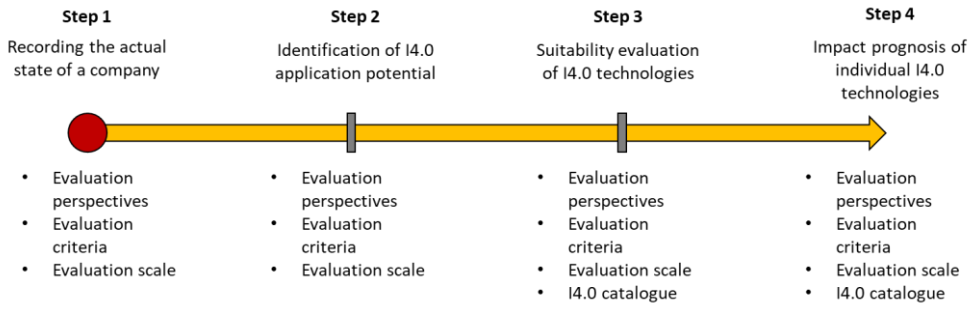

Figure 2. Operation principle of the Potential Model and components used

3.2 Main Elements of the Potential Model

According to **Chapter 2** the main objective of this publication is the detailed introduction of the development and provision of the PM core elements, which in summary is a novel methodical solution regarding I4.0 maturity analysis and technology assessment (**Chapter 1.1**). The mentioned core elements are the evaluation criteria, the evaluation scale, the evaluation scheme as well as the I4.0 technology catalogue. In this chapter the PM elements are described in detail.

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3.2.1 Evaluation Criteria

The evaluation criteria represent the motivation that can fundamentally drive the implementation of an Industry 4.0 technology from an industrial point of view. As a core element of the PM they serve to determine the current state or maturity level (**Chapter 1.1**) of a company under aspects of I4.0 and to determine as well as visualise the potential effects of the implementation of various I4.0 technologies. In **Figure 3** the 30 evaluation criteria of the PM are shown.

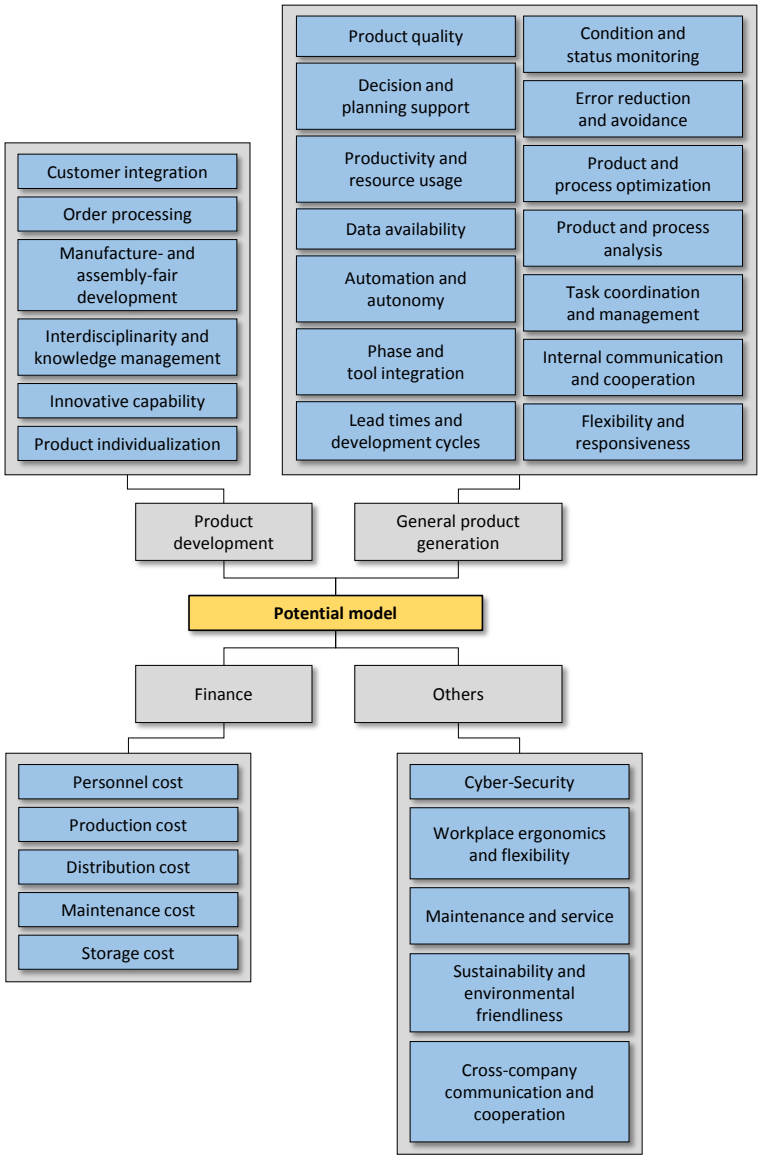

Figure 3. Industrial motivation to implement I4.0 - Potential Model Evaluation Criteria

Identification of the evaluation criteria

Based on the research of Schneider et al. (2020) a strategic and extensive literature research as well as several surveys were carried out in order to identify and optimize the 30 evaluation criteria. In the course of the research, both scientific papers and industrial articles, which had a reference to Industry 4.0 or to the fundamentals of company and technology assessment, were analysed. A central principle of identifying the evaluation criteria was the cross-domain view of a company beyond production. The evaluation criteria represent aspects for the implementation of I4.0 and could be derived from literature about the obstacles of the implementation of I4.0 in SMEs (Erol et al., 2016; Matt et al., 2020; Vaidya et al., 2018), the overall potentials of I4.0 (Blunck and Werthmann, 2017; McKinsey Digital, 2015; Wichmann et al., 2019) and the characteristics as well as current hurdles of the phase of product development (Sharafi, 2013; Ulrich and Eppinger, 2012; Vietor et al., 2015). Due to the high relevance of product development (PD) for the entire product generation process and the insufficient addressing of this phase by research in the field of I4.0 (**Chapter 1.1**), special attention was given to

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PD during the criteria identification and their structuring as shown in **Figure 3**. Based on surveys conducted within industrial enterprise associations, the selection of representative evaluation criteria could be validated and improved with regard to their actual industrial relevance.

Structuring of the evaluation criteria

The purpose of structuring the evaluation criteria is to simplify the understanding of the PM application as well as the evaluation criteria themselves and to improve clarity. The 30 evaluation criteria were assigned to the perspectives "Product Development", "Finance" and "General Product Generation". If the assignment of a criterion to one of these three perspectives was not clearly apparent, they were subdivided under "Others" (**Figure 3**). The PM structuring is based on the perspectives of the "Balanced Score Card" (BSC) - an established method for the holistic consideration of companies and cross-domain processes. (Erdmann, 2013; Schneider et al., 2020)

Overall value of the evaluation criteria

The PM assessment criteria, identified and validated based on literature research and surveys (**Figure 3**), are used for the maturity analysis of a company and in the course of the I4.0 technology assessment. They enable the self-assessment of the actual states of a company by the users of the PM and ensure the output of highly individualised results regarding the suitability of different I4.0 technologies depending on the individual input data or actual states. In relation to the current state of research (**Chapter 1.1**), this approach is novel and highly relevant. The evaluation criteria enable the combination of individualised maturity analysis and technology assessment in a single method.

3.2.2 Industry 4.0 Technology Catalogue

The I4.0 catalogue contains information about the individual technologies considered in the Potential Model and provides it in the course of suitability-evaluation (**Chapter 3.1**, **Figure 1**). The information contained in the catalogue includes, inter alia, the functional description, the field of action, the literature reference and industrial application examples. Referring to the "Classification Model" (CM) published by Inkermann et al. (Inkermann et al., 2019), the I4.0 catalogue also contains the information which elements of the CM are covered by the individual technologies. This serves to clarify the question of why the technologies in the catalogue are Industry 4.0.

In total, the I4.0 catalogue contains specific information on the following 21 technologies:

- Autonomous driverless transport systems
- Augmented Reality (AR) in product development
- AR in commissioning
- AR in assembly
- AR in quality assurance
- Demand-driven material flow
- Design automation
- Digital and networking integration platform
- Digital integration platform and customer-specific order processing
- Predictive maintenance
- Predictive maintenance and smart maintenance management
- Product status overview in value added networks
- Virtual start-up
- Virtual Reality (VR) for product visualisation
- Ergonomics analysis in product development
- Human-Robot-Collaboration
- Exoskeletons for lifting and overhead work
- Digital shift planning and task coordination
- Smart products for targeted and customer-integrated product development
- Smart products as a service

Identification of the I4.0 technologies

Using the CM to justify the inclusion of a technology in the Industry 4.0 technology catalogue of the PM, a total of 21 entries were recorded in the catalogue. These entries were based on three student theses in which systematic literature research on I4.0 technologies was carried out and a specially

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conducted, further research in which both scientific publications and industrial articles were analysed. The Industry 4.0 technologies identified in the course of the research work were examined, based on the CM, with regard to their I4.0 elements and described in the technology catalogue according to the CM analysis. Both the name and the total number of technologies indicate that the catalogue lists a superordinate instance of I4.0 technologies. Thus, no specific technological solutions of I4.0 are considered, such as the AR technology of a particular manufacturer, which at a sensory level differs greatly from the AR technologies of competitors in terms of application and design. The I4.0 technologies considered in the PM are described on a functional level and thus summarise the varying technological solution approaches of industrial suppliers. Only in cases where the technological field of action has radically changed the function and the application objective of an I4.0 technology, it was recorded as an additional I4.0 entry (e.g. AR technology). Since a *rough-quantitative* assessment of I4.0 technologies is carried out with the help of the Potential Model and since the objective is to provide the user with an initial orientation in the field of Industry 4.0 (see **Chapter 1.3** and **Chapter 2**), the choice of the I4.0 technology description at the functional level is purposeful and sufficient.

Structuring and Utilization of the I4.0 catalogue

With the objective of issuing a technology recommendation for the individual current state of a company and visualising the potential effects of a considered technology, there is a link between the evaluation criteria (**Chapter 3.2.1**) and the I4.0 catalogue. This link is realized by the evaluation scale of the PM. Thus, the technology catalogue records the potential effects of each I4.0 technology on the individual evaluation criteria on a rough quantitative level. The potential effects recorded in the I4.0 catalogue are based on expert estimations and were determined according to the knowledge extracted from the literature research. Since the PM operates on a rough-quantitative assessment level and is primarily intended to provide users with an orientation on possible strategic actions in the field of I4.0, the expert estimations are entirely sufficient. The structuring of the data is exemplary shown in **Table 1**. In the first line, the I4.0 technologies are listed from left to right. The third column shows the evaluation criteria - structured according to the evaluation perspectives. In the cells below the respective I4.0 technologies, the potential technological impacts were documented and are available for retrieval in the course of the PM application.

Table 1. Analogous data structuring of the I4.0 technology catalogue

Potential impact of I4.0 technologies on the evaluation criteria			*Autonomous driverless transport systems*	*AR in product development*	…
Perspectives and criteria for evaluating Industry 4.0 technologies	*Finance*	Personnel costs	2	0	…
		…	…	…	…
	General product generation	Product quality	0	3	…
		…	…	…	…
	Product Development	Customer integration	0	3	…
		Order processing	0	2	…
		…	…	…	…
	Others	Sustainability	1	0	…
		…	…	…	…

The potential I4.0 effects on the individual PM evaluation criteria listed in the catalogue can be positive, neutral or negative. As shown in **Table 1**, the potential I4.0 effects link the 21 technologies listed in the I4.0 catalogue to the 30 PM evaluation criteria (**Chapter 3.2.1**). A total of 630 potential I4.0 effects of the technologies on the evaluation criteria are recorded in the I4.0 catalogue.

3.2.3 Execution of the evaluation - scale and scheme

Due to the limited extent of this publication the evaluation formulas will not be discussed in detail in this chapter. The objective is instead to convey the evaluation principle and the central evaluation elements of the I4.0 technology suitability evaluation.

Evaluation scale - Link between I4.0 technologies and evaluation criteria

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The evaluation scale is the interface between I4.0 technologies and evaluation criteria in the context of the PM and extends from 1 to 5. The state 1 reflects a very inadequate and 5 a very good fulfilment of an evaluation criterion by a company. It is an "end-point defined Likert Scale" (Thielsch and Brandenburg, 2012), whose established application is suitable for the use of the rough-quantitative evaluation of the PM. Based on this scale, the user of the PM estimates the actual state or rather the actual fulfilment of each evaluation criterion. Furthermore, the I4.0 catalogue describes the potential positive, neutral or negative effects of the individual I4.0 technologies based on this evaluation scale (**Chapter 3.2.2**, **Table 1**). In this way, the actual and target status (potential I4.0 status) can be merged. Due to the comparability by using the same evaluation scale, the potential effects of the I4.0 can be visualised in the PM and consequently be better understood by the user. In this way, good and simple comprehensibility is maintained during the application of the PM and a strong individuality of the results is enabled as well as the linking between I4.0 technologies and evaluation criteria.

I4.0 Technology evaluation scheme

The I4.0 suitability-evaluation resulting from the integration of the actual and target state is based on several complex evaluation formulas that were developed specifically for this purpose. For the value integration, these formulas include the four perspectives listed below in order to make the evaluation of the I4.0 technologies as targeted as possible.

- Potential impact of I4.0 technologies (I4.0 Catalogue)
- Integration of actual and target status
- Potential delta generated by I4.0 depending on the actual company state and the limits of the Likert scale
- Overall actual state of the company

If a criterion is already optimally fulfilled in a company (5) and at the same time not addressed by an I4.0 technology (0), the simple combination of actual and target state suggests a strong I4.0 improvement potential, which de facto does not exist. During the evaluation process this is taken into account by considering the potential delta created by an I4.0 technology depending on the existing actual state and the limits of the Likert scale. Another perspective that is considered when evaluating the suitability of I4.0 technologies is the overall condition of the company with regard to the fulfilment of the evaluation criteria. If, for example, the company as a whole is already very well positioned with regard to the criteria of the I4.0 implementation, there is mathematically less potential for improvement through the I4.0 technologies due to the limits of the Likert scale. This is indicated to the user as a hint when visualising the evaluation results and taken up in the underlying evaluation formulas. In the course of applying the PM and indicating the actual state of the individual evaluation criteria, the user can optionally give particular weight to individual evaluation criteria and define them as "focal points". To the I4.0 impacts on these focal points will then be given special weight in the course of the suitability evaluation of the technologies and again explicitly analysed under the four perspectives described above.

4 APPLICATION VARIANTS OF THE POTENTIAL MODEL

The application of the PM is carried out software-based with the help of a spreadsheet programme. The basic application method described in **Chapter 3.1** (**Figure 2**), which has already been published by Schneider et al. (2020), is fully taken up in the course of applying the software-based PM. Since the PM is designed in particular to support SMEs in the implementation of I4.0, it was developed with the intend to enable the user to completely self-apply the PM without involvement of experts. This is supported by a corresponding guideline. In addition to ensuring self-application, the PM was developed with the intend to require a minimum monetary and temporal effort during application in order to address hurdle of cost-benefit ratio (**Chapter 1.3**). In order to design the application of the PM as practicable as possible, for step 1 of the method application (**Figure 2**) the PM was realised as a graphical representation in the form of a circular model, as it is also presented in the publication by Schneider et al. (2020). In this way, the user-side estimation of the actual states of the individual evaluation criteria can take place in the course of a (self-organised) workshop with several participants. The assessments can then be transferred to the software-based PM for evaluation. Thus, in addition to the self-organised individual application, the workshop-based PM application is also made possible. Due to the short time required by the evaluation process of the PM there is nothing to prevent a joint discussion of the results within the course of the workshops.

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5 SUMMARY AND FURTHER RESEARCH

This publication continues the work on the Potential Model (PM) by Schneider et al. (2020). While the publication by Schneider et al. (2020) published the basic functionality of the PM in the form of a conceptual solution approach, this publication focuses on the elaboration of the central elements of the PM. These are the evaluation criteria, the evaluation scale, the evaluation scheme and the I4.0 technology catalogue. The outcome of this publication is the presentation of an assessment methodology that links assessment criteria to specific Industry 4.0 technologies and integrates the research focus of methodological support for maturity analysis and technology assessment. The method addresses current hurdles of SMEs in the implementation of Industry 4.0 and answers both industrial and scientific questions (**Chapter 2**). In the course of applying the PM, which is conceptually presented in the publication by Schneider et al. (2020) and methodologically elaborated in the present publication, answers are given as to which criteria can be used to evaluate Industry 4.0 technologies (**Chapter 3.2.1**). Furthermore, this publication addresses which technologies are used at a functional level in the context of I4.0 for suitability assessment and why they can be described as "Industry 4.0" (**Chapter 3.2.2**). The detailed explanation of the evaluation scheme underlying the application of the PM answers the question of how evaluation criteria and I4.0 technologies can be methodically linked and brought together (**Chapter 3.2.3**). The contents of the PM presented in this paper are currently taken into account in the context of a dissertation, whereby the development of an I4.0 method and knowledge platform is taking place. This platform aims in particular to support SMEs in the evaluation and implementation of I4.0 technologies, whereby methodical and freely accessible tools ensure individualised assistance with minimum financial and time expenditure on the part of the SMEs.

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