Industry 4.0 Maturity Models for SMES: Lessons Learned and Recommendations for Their Adoption Based on the Literature Review

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Abstract

Since the launch of Industry 4.0 in 2011, its understanding has been driving science and business, and in the case of small and medium-sized enterprises (SMEs), with increasing intensity. That Industry 4.0 is not just a simple transformation and demands immense efforts from companies to implement it, is demonstrated not only by scientific publications, but also by numerous patents/products and editorials in journals. Maturity models (MMs) and readiness models (RMs) for Industry 4.0 are a frequently chosen issue to approach the topic (of implementation). In this paper, based on a structured literature review, 78 models were identified and analyzed, resulting in a set of recommendations for the application of those models by SMEs. Theoretically, this paper contributes to increase knowledge in the area of digitalization, compiling and classifying the different models to support the digital transition. This paper may help practitioners choosing a suitable model for their company, namely SMEs where it is difficult to find solutions.

Keywords
Industry 4.0, Maturity model, Readiness model, SME, small and medium-sized enterprises.

1. Introduction

The 2011 Hannover Messe classified the industrial age into Industry 3.0 and Industry 4.0. Since then, science and industry have been trying to give the term structure, define and delimit it (Dikhanbayeva et al. 2020; Schumacher et al. 2016). The focus is on new components or components applied in new constellations, such as big data and analytics (BD/BDA), Internet of things (IoT) and cyber-physical systems (CPS), (Kumar et al. 2020). These form a network all-round exchange of data, which is not only limited to the technical aspects, but also includes management, strategy, innovation, culture & organizational aspects (Ganzarain & Errasti 2016; Yue et al. 2019).

Industry 4.0 vision forces real-time multilateral communication between CPS and humans as autonomous, self-optimizing and intelligent processes (Santos & Martinho 2019; Schuh et al. 2017). However, entering this new world requires new ways of thinking in companies, as it means moving away from traditional production structures that focus primarily on reducing manufacturing costs and time to market (Lin et al. 2020). These new approaches often have not yet been truly understood by companies (Krowas & Riedel 2019). According to Rauch et al. (2019), entering Industry 4.0 world is particularly challenging for SMEs, where major barriers such as high investment costs in high-end software (Li & Lau 2019) and the lack of IT and engineering professionals (Mittal et al. 2018) among others, must be overcome. Although SMEs account for over 90% of companies in many countries (European Commission,

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2021a), SMEs are not yet convinced of the benefits of Industry 4.0 concepts (Pech & Vrchota 2020), which makes the research field particularly necessary. Peukert et al. (2020, p. 1) become clear and criticize, "that new ways have to be found to encourage SMEs to take the first steps towards Industry 4.0".

Regardless of company size, MMs/RMs are currently favored to approach the topic of Industry 4.0 (Bertolini et al., 2019). With both approaches, the current status of an organization is systematically assessed (Knackstedt et al. 2009; Pessl et al. 2017) due to various disciplines corresponding to Industry 4.0 readiness/maturity. From the deviations to the ideal, the skills still to be acquired can then be derived as a roadmap in projects, milestones and to do's for achieving the desired Industry 4.0 target level (Pirola et al. 2019).

Through a structured literature review (LR), the current state of research is determined and presented in an intensive discussion of the findings and recommendations. The overarching research question is: "*Which Industry 4.0 maturity or readiness models exist and what insights/recommendations for use in SMEs can be derived from them?*" This aims to improve MM/RM and reduce the hurdles for its use by SMEs.

2. State-of-the-art-background

Relevant terminologies are described to support the research background and provide clarity in terms of their understanding in this paper.

2.1 Industry 4.0

In addition to BD/BDA, IoT and CPS, Industry 4.0 also stands for autonomous robots, simulation, additive manufacturing, augmented reality and Internet of Services (Bertolini et al. 2019) through which a high degree of supply chain (SC) integration with improved communication is achieved. This goes hand in hand with the goal of improving the quality of the products and processes offered, to serve customer requirements (Odważny et al. 2019). Real-time feedback achieved by the technologies promotes active control toward self-organized and autonomous systems (Krowas & Riedel, 2019) and a continuously digitized, robotized & automated production environment (Basl & Doucek 2019) in which intelligent products including manufacturing documentation are created (BMWi 2021b). According to Schuh et al. (2017), the economic potential of Industry 4.0 lies primarily in accelerating entrepreneurial decision-making & adaptation processes, while according to Lichtblau et al. (2015) it lies in maximizing the efficiency of production systems in which flexibility and adherence to schedules are increased and lead times are reduced.

With some of the most advanced economies already using Industry 4.0 to increase productivity and flexibility (Posada et al., 2015), competition is increasing (Kumar et al. 2020) and so is the pressure to take action to drive seamless horizontal and vertical integration across the enterprise and SC. This is undoubtedly a challenging goal that only about 10% of global manufacturing companies currently achieve as digital champions (Vedsø et al. 2018). This is partly because digital transformation is a critical, strategic decision (Schumacher et al. 2016) and requires strong capabilities (Dikhanbayeva et al., 2020) and multidisciplinary activities (Colli et al. 2019).

2.2 Small and medium sized enterprises

SMEs form the economic backbone of the entire world. With estimated 400 million individual companies worldwide, they account for approximately 2/3 of all jobs (United Nations 2019). This also applies to the European Union, where 99% of all companies are classified as SMEs (European Commission, 2021a), according to the criteria of number of employees (10 - 249), turnover (2 - 50 M€) and balance sheet total (2 - 43 M€).

Especially for SMEs, the digital transformation poses significant challenges (Rauch et al. 2019). They mostly are unable to afford the initial high financial investment to build up CPS and IoT (Pessl et al. 2017) or employment costs for IT and engineering talent as well as maintenance costs for IT infrastructures (Li & Lau 2019).

SMEs are generally characterized by intensive networking in the regional environment, high flexibility and versatility in meeting customer requirements, and high innovative capacity (BMWi 2021a). In this context, SMEs rely on committed and capable employees, a low level of bureaucracy and coordination, customized products and close customer relationships (Pech & Vrchota 2020). SMEs focus on their strengths, which are often tradition-related, and develop them incrementally rather than disruptively as their investment strategy also tends to be conservative. Moreover, according to Ingaldi and Ulewicz (2020), SMEs also struggle with a rather narrow product portfolio, moderately automated or autonomous production systems, and limited strategic experience. Regarding to Mittal et al.

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(2018) the path to digital transformation is also hampered by limited Industry 4.0 knowledge and lack of experience. These challenges could have a paralyzing effect on SMEs and prevent them from starting digital transformation.

2.3 Maturity models / Readiness models

Assessment models like MMs/RMs are mostly based on Capability Maturity Model (CMM), which were developed in the 1980s in an initiative of the U.S. Department of Defence at the Software Engineering Institute (SEI) in Pittsburgh (Knackstedt et al. 2009). While readiness stands for the preparedness to be able to initiate the transformation process (Lakmali et al. 2020), maturity is downstream of this and stands for the level that is already reached (Schumacher et al., 2016). A MM "represent a theory of stage-based evolution (…) [by] (…) describing stages and maturation path" (Finnerty et al.,
2017, p. 7). Regarding to Industry 4.0, MM/RM are particularly useful to understand one's own company in the specific context and to develop appropriate development plans (Becker et al. 2009).

3. Methodology

A structured literature review (LR), adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology developed by Moher and Liberti (2009) is applied. PRISMA is an evidence-based reporting standard suitable for critical appraisal (Hizam-Hanafiah et al. 2020). In this case, the LR provides the opportunity to identify the research available in the search focus (Tranfield et al. 2003). Based on search criteria listed in table 1, 308 results were identified via SCOPUS and 37 via Web of Science. Using snowball analysis, 48 further publications were identified after full-text reading of the results and included in the explanatory analysis process. Although this study addresses the use of MM/RM in context of SMEs, this has been deliberately excluded in the construction of the keyword string. The subsequent filtering allows the MM/RM to be assigned to the company sizes and shows differences between the approaches / recommendations for SMEs and Multinational Enterprises (MNEs).

Table 1. Database research criteria

Category	Specification
Language	English, German
Timeline	2010 – 2020
Database	Scopus, Web of Science
Subject area	Engineering, Computer Science
Literature type	Article, Conference Paper, Review, Conference review
Keyword Search	"Industry 4.0" OR "Industrie 4.0" OR "I 4.0" OR "I4" OR "I4.0" OR "Vierte Industrielle Revol*" OR "fourth industrial revol*" OR "4th industrial revolution" OR "Smart manufact*" OR "smart producti*" OR "smart factor*" OR "digiti?ation" OR "digitali?ation" AND "Maturity model" OR "CMMI" OR "Reifegrad*" OR "Capability Maturity Model Integration" OR "readiness index" OR "degree of readiness" OR "assessment model" OR "readiness model"

4. Results and Discussion based on explanatory analysis

4.1 Quantitative analysis

The analysis (text and references) of the 112 publications identified using the structured LR (only those documents who's abstract and headings contained clear arguments that could be linked to the research question were analysed) found a total of 83 models (MM, RM, and others). Five of these results were not considered further due to various aspects. In case of "Industry 4.0 Procedure Model" by Merz et al. (2016) and "Industry 4.0 Roadmap: Implementation for SMEs" by Cotrino et al. (2020) because they are not assessment models but process or implementation guides. "Empowerment and Implementation Strategies for Industry 4.0" by Lanza et al. (2016) and "Towards a framework for Assessing the Maturity of Manufacturing Companies in Industry 4.0. Adoption" by Scremin et al. (2018) were excluded as the required papers are not freely available. The "Smart Manufacturing Maturity Assessment Framework" by Yue et al. (2019) was excluded as it is a high-level categorization model. Remaining 78 models are listed in table 3 and 4. For applicability in SMEs, the models were evaluated against relevant decision criteria, shown in table 2.

Table 2. Categories for model usability in SMEs

Category	Code	Decision criteria
designed for SME	A	Model is designed for SMEs requirement and the utilization in SMEs.
ok for SME	B	Model is not specifically designed for SMEs, but can be adopted for SMEs.

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		No or just low additional costs required to make the model usable in SMEs. Resources to understand / handle the model are available in SMEs.
not ok for SME	C	Model is designed for countries, regions or other applications (not enterprises). Model requires support from consulting company (high additional cost expected). Skills to understand / utilize the model are not likely to be present in SMEs. Model is not fully developed / documented.

Table 3. Models with an academic origin

Model	Year	Author	SME usability	Type	MM/RM addresses	# of stages	# of dimension
Business Intelligence Maturity Model (BMMI)	2014	Näslund et al.	C	MM	enterprise	5	2
SMSRA - Manufacturing Readiness Index	2015	Jung et al.	C	RM	enterprise	6	4
RAMI 4.0: Reference Architecture Model for Industry 4.0	2016	Plattform Industry 4.0	C	other	Industry	undefined	differs
Maturity and Readiness Model for Industry 4.0 Strategy	2016	Akdil et al.	B	MM	Industry	4	3
Assessment Model for Organizational Adoption of Industry 4.0	2016	Keskin et al.	B	MM	enterprise	5	6
Roadmap Industry 4.0 - Implementation Guideline	2016	Pessl et al.	B	MM	enterprise	5	5
SIMMI 4.0: System Integration Maturity Model Industry 4.0	2016	Leyh et al.	B	MM	enterprise	5	4
Maturity Model Industry 4.0	2016	Jodlbauer & Schagerl	B	MM	enterprise	11	3
Categorical Framework of Manufacturing for Industry 4.0	2016	Quin et al.	B	RM	enterprise	3	3
GPMI4.0 (Generic Procedure Model to introduce I 4.0 in SMEs)	2016	Wang et al.	A	other	enterprise	5	undefined
Three stages Maturity Model in SMEs towards Industry 4.0	2016	Ganzarain & Errasti	A	MM	enterprise	5	undefined
Digital Maturity Model	2016	Back & Berghaus	B	MM	enterprise	undefined	9
A digital Maturity Model for Telecom. Service Providers	2016	Valdez de Leon, O.	B	MM	enterprise	6	7
Industry 4.0 Readiness Model for Tool Management	2017	Rafael et al.	A	MM	enterprise	6	6
Assessment Model for Industry 4.0	2017	Gökalp et al.	B	MM	enterprise	6	5
MM for Digitalization in Manufacturing Industry's Supply Chain	2017	Klötzer & Pflaum	B	MM	enterprise	5	2
M2DDM - A Maturity Model for Data-Driven Manufacturing	2017	Weber et al.	C	MM	enterprise	6	6
DREAMY: Digital Readiness Assessment Maturity Model	2017	De Carolis et al.	B	MM	enterprise	5	5
IoT technological Maturity Assessment Scorecard	2017	Jæger & Halse	C	MM	enterprise	8	3
Smart service strategies in Industry 4.0	2017	Jarrahi et al.	B	RM	enterprise	4	9

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ANP - Analytic Network Process	2017	Lee et al.	C	MM	enterprise	5	4
Digitalization Maturity Model for the Manufacturing Sector	2017	Canetta et al.	B	MM	enterprise	4	5
An Industry 4.0 readiness assessment tool (2016)	2017	Agca et al.	B	MM	enterprise	5	6
Industry 4.0 Readiness Evaluation Model for Manufacturing	2018	Viharos et al.	C	RM	Industry	undefined	8
BMS SIRM (Smart Industry Research Model)	2018	Jongbloed et al.	C	other	Industry	4	4
SM³E: Smart manufacturing maturity model for SMEs	2018	Mittal et al.	A	MM	enterprise	5	5
SMEs MM Assessment of IR4.0 Digital Transformation	2018	Hamidi et al.	A	MM	enterprise	6	6
E-Business Industry 4.0 Readiness Model	2018	Demeter et al.	C	MM	country	undefined	3
Industry 4.0 Future Readiness Index	2018	Botha, A.	C	RM	enterprise	differs	6
Industry 4.0 Maturity Model	2018	Bibby & Dehe	C	MM	enterprise	4	3
Industry 4.0 Readiness Evaluation for Manufacturing Enterprises	2018	Basl & Doucek	C	RM	other	undefined	7
Smart Factory Implementation and Process Innovation	2018	Sjödin et al.	C	MM	enterprise	4	3
Industry 4.0 maturity model for the delivery process in SCs	2018	Asdecker & Felch	A	MM	enterprise	5	3
Digital supply chain model in Industry 4.0	2018	Garay-Rondero et al.	C	RM	enterprise	undefined	6
Industry 4.0 migration model	2018	Leineweber et al.	B	MM	enterprise	undefined	3
MTMM (Manufacturing Technology Maturity Model)	2018	Gracel & Łebkowski	B	MM	enterprise	4	8
DRL 4.0 Model (Digital Readiness Level)	2018	Pirola et al.	A	RM	enterprise	5	4
Maturity model of digitization for SMEs	2018	Blatz et al.	A	MM	enterprise	5	6
Industry 4.0 Maturity of german companies	2018	Bittighofer et al.	C	RM	country	5	6
Industry 4.0 maturity model proposal	2019	Santos & Martinho	B	MM	enterprise	6	5
PIM 4.0: Industry 4.0 maturity model	2019	Azevedo & Santiago	C	MM	enterprise	undefined	6
Planning Guideline and MM for Intra-logistics 4.0 in SME	2019	Krowas & Riedel	A	MM	enterprise	5	4
360 DMA (Digital Maturity Assessment)	2019	Colli et al.	C	MM	enterprise	5	5
The degree of readiness for implementation of I 4.0	2019	Pacchini et al.	B	RM	enterprise	6	8
Industry 4.0 Maturity Model Munich (I4-MMM)	2019	Puchan et al.	A	MM	enterprise	5	5
Assessing Industry 4.0 Maturity: An Essential Scale for SMEs	2019	Trotta & Garengo	A	MM	enterprise	5	5
Smart SMEs 4.0 Readiness model	2019	Chonsawat & Sopadang	A	MM	enterprise	5	5

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Digital Performance Assessment Model	2019	Gamache et al.	A	MM	enterprise	5	6
A Maturity Model for Logistics 4.0	2020	Facchini et al.	B	MM	enterprise	5	7
MM for assessing the implementation of Industry 4.0	2020	Wagire et al.	B	MM	enterprise	4	7
Digital Transformation Maturity Model for IT Companies	2020	Gollhardt et al.	B	MM	enterprise	5	5
Maturity Level-Based Assessment Tool of Industry 4.0 for SMEs	2020	Rauch et al.	A	MM	enterprise	5	5
CCMS (Company CoMpaSs)	2020	Nick et al.	A	MM	enterprise	5	3
Industry 4.0 MM for Operations and SCM	2021	Caiado et al.	C	MM	enterprise	5	7

Table 4. Models with a practitioner origin

Model	Year	Author	SME usability	Type	MM/RM addresses	# of stages	# of dimensions
Industry 4.0 Readiness Index	2014	Blanchet et al.	C	RM	country	5	2
Connected Enterprise Maturity Model	2014	Rockwell Automation	C	MM	enterprise	5	undefined
Big data & Analytics Maturity Model	2014	Nott et al.	C	MM	enterprise	4	6
IMPULS - Industry 4.0 Readiness	2015	Lichtblau et al.	B	MM	enterprise	6	6
Fraunhofer Industry 4.0 Layer Model	2016	Neugebauer et al.	B	MM	enterprise	5	3
Industry 4.0: Enabling Digital Operations Self-Assessment	2016	Geissbauer et al.	B	MM	enterprise	4	6
Industry 4.0 Maturity Model	2016	Schumacher et al.	B	MM	enterprise	5	9
Guidelines for Industry 4.0	2016	Anderl et al.	A	MM	enterprise	5	differs
Digital Maturity Model 4.0	2016	Gill & VanBoskirk	C	MM	enterprise	4	4
Reference Architecture and Maturity Level in CPSs	2016	Westermann et al.	C	MM	enterprise	5	7
Digital Readiness Assessment (DRA) - KPMG	2016	Wallner et al.	C	MM	enterprise	undefined	7
ACATECH Industry 4.0 Maturity Index	2017	Schuh et al.	C	MM	enterprise	6	4
Readiness for Industry 4.0	2018	Horvat et al.	B	RM	enterprise	4	5
Readiness I4.0 (Benchmarking)	2018	Lerch & Jäger	B	RM	enterprise	6	9
Digital Capability Assessment (DCA) - Accenture	2018	Accenture	C	RM	enterprise	undefined	5
Digital Acceleration Index (DAI) - BCG	2018	BCG	C	RM	enterprise	undefined	4
Digital Maturity Model (DMM) - Deloitte	2018	Deloitte	C	MM	enterprise	undefined	5
Digital Readiness Assessment - Ernst & Young	2018	Ernst & Young	C	RM	enterprise	undefined	9
Digital Capabilities (DC) - McKinsey & Company	2018	McKinsey	C	MM	enterprise	undefined	6
Smart Manufacturing Kaizen Level (SKML)	2019	Shi et al.	C	MM	enterprise	4	4
Industry 4.0 realization model	2019	Schumacher et al.	C	MM	enterprise	4	8

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Self-Assessment Tool for Industry 4.0	2019	Brozzi et al.	A	RM	enterprise	5	3
The Smart Industry Readiness Index	2019	Kiang et al.	B	MM	enterprise	differs	3
A Readiness Model in the Context of Industry 4.0	2020	Nausch et al.	B	RM	enterprise	5	4

As figure 1 shows, although 17 models were designed specifically for use in SMEs (21%), the majority of models were developed for MNEs. Of the 79%, 29 models can be adapted for use in SMEs with restrictions, while 32 models are categorically not suitable. What is striking is the similar distribution of MM/RM that are suitable for SMEs compared to the models that SMEs cannot/should not use. Here, the proportion of RMs is significantly higher, indicating that RMs are more complex. It is also apparent that for RMs used in an early phase of the transformation to an Industry 4.0 company, the necessary data basis is not available in SMEs and RMs are therefore less suitable.

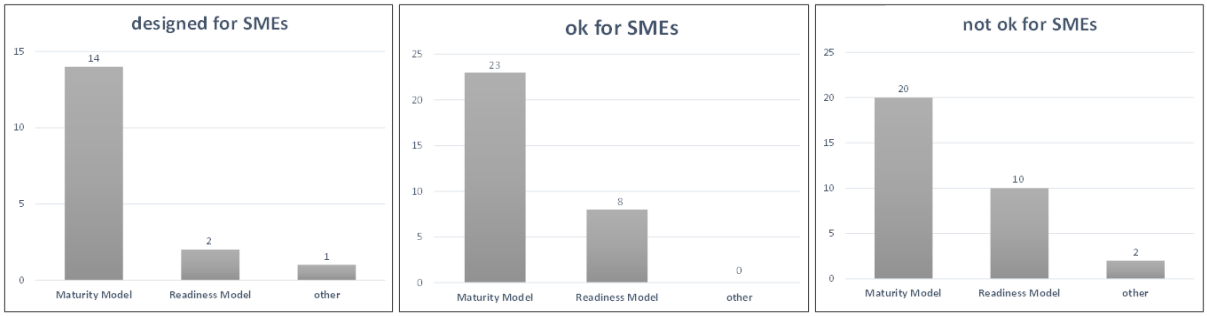

Figure 1. Models related to usability in SMEs

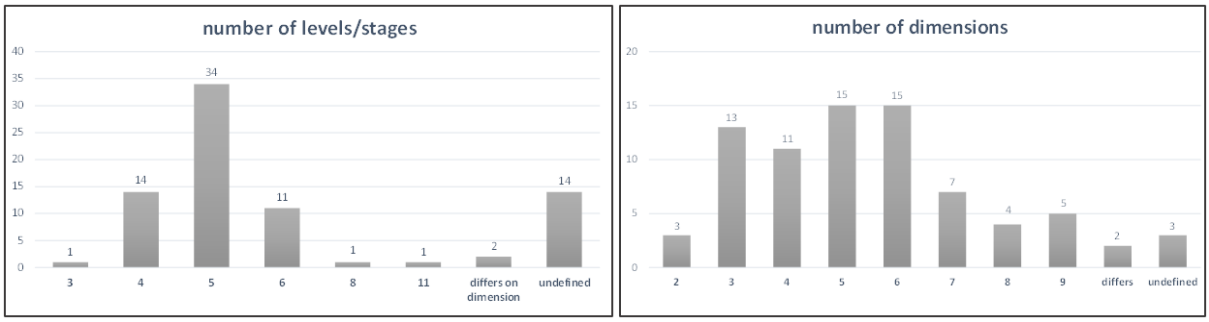

Figure 2. number of level / stages and dimensions of the models

As shown in Figure 2, the use of 5 maturity levels (the majority by using a five-point Likert scale) has become established. It is concluded that a coarser classification offers too little scope for a step-by-step development of the companies, while a finer classification requires a more differentiated assessment, which, however, presupposes a significantly higher Industry 4.0 understanding in practical implementation. With regard to the dimensions, it should be noted that the median number of dimensions used is between 4 and 5 (main dimensions). Occasionally, multiple sub-dimensions or maturity items are also embedded in models, e.g. (Gamache et al., 2019; Leinweber et al., 2018). It can be inferred that fewer dimensions tend to provide too coarse an assessment grid without the necessary sharpness, while too many dimensions lead to increased effort in model calculation and editing.

4.2 Findings based on contend analysis

A total of 143 findings and recommendations related to maturity models and readiness models for Industry 4.0 were found in the publications. These already scientifically validated information can support the design and development of MM/RM to reach the next level if taken into account. Based on and extending Schumacher et al. (2016), clusters are set and the results are analyzed and discussed in the following.

4.2.1 Findings regarding dimensions and structural approach of MMs/RMs

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Several overview analyses of Industry 4.0 MM have been undertaken. Most of them are based on Capability Maturity Model Integration CMMI) from Software Engineering Institute or the work of Crosby (1979) (Achi et al., 2016). It is noticeable that the vast majority of the models place a clear focus on the technological aspects and that organizational, cultural, people-related, leadership and process-related dimensions are of secondary importance (Hizam-Hanafiah et al., 2020; Mittal, Romero, et al., 2018). Furthermore, the question of which Industry 4.0 concepts might be suitable for different types of companies according to their different sizes is still unanswered (Rauch et al., 2019).

Industry 4.0 is not a rigid entity and it evolves just like the way we deal with and understand it. Industry 4.0 revolution is therefore followed by Industry 4.0 evolutions. For SMEs, it can thus be stated that more recent maturity models can score points by including these evolutionary developments in the assessment system. The consideration of an appropriate model should take this into account.

4.2.2 Criticism to MMs/RMs

The most powerful criticisms regarding MM/RM comes from Vijaya Kumar (2020), who argues that the models developed have not yet been tested on real needs or have been tested far too little. In their work with focus on manufacturing companies (Leyh et al. 2018; Nick et al., 2020) complain the limited view of the models and the orientation on the internal organization and its process, although Industry 4.0 explicitly stands for horizontal and vertical linkage. The influence of user opinion, i.e., the subjectivity in questionnaires and assessments, does not correspond to the objective measurement suggested by maturity models (Bertolini et al. 2019). A statement to which Thordsen (2020) can contribute, that the understanding of digitalization is also only specified by a few reference models and thus corresponds to the subjective interpretation of the reader. A main problem with available models is brought to light by Kolla et al. (2019), who point out that MM/RM are usually designed for MNEs who can deal with generic MM/RM (availability of resources and a high Industry 4.0 knowledge) or options to hire consulting firms, SMEs often have great difficulties to apply these maturity models (de Jesus & Lima, 2020). Mittal et al. (2020) found in a high-profile study that Industry 4.0 startup conditions are difficult for SMEs compared to MNEs, as barriers to entry have not even been overcome (including a frequent lack of an IT department, organizational structure, and employee skills, and insufficient technical equipment exists). They are therefore mostly grouped at the lowest level (level "0") of Industry 4.0 MMs/RMs. However, further analysis also shows that it is precisely the leap from the lowest to the next higher level that requires greater effort than, for example, the leap from level "1" to level "2" (Mittal et al., 2020).

Simetinger (2020) criticizes the structure of MMs/RMs and speaks of the phenomenon of a (predetermined) "breaking point". This means that logical dependencies in the dimensions do not allow them to be developed independently. "These logical dependencies determine a critical path of criteria that must be met by the organization to continue in its own increasing maturity" (Simetinger & Zhang 2020). In addition, specific criticisms are raised that few models include HR aspects (Trotta & Garengo, 2019) and that cross-cutting dimensions such as IT security are not elaborated in the models (Basl & Doucek 2019).

As described above, MM/RM for SMEs is a proven and suitable option for entering the world of Industry 4.0, although it is fraught with definitions, as many MM/RM are rather designed for MNEs. Therefore, the objectivity of the derived results should always be seen in context and questioned, as according to a result of the SLR, the models have not yet been sufficiently tested and verified. In addition, the subjectivity or subjective interpretation in the models is a pitfall resulting from the danger of evaluating the company-specific circumstances too positively or too negatively. A fact-neutral assessment that is formally oriented towards standards and definitions has not yet been achieved and SMEs therefore need a solid basic understanding of Industry 4.0 in order not to suffer shipwreck in the interpretation. Another critical point is the complexity of Industry 4.0 MM/RM for SMEs. Especially in manufacturing SMEs, where the focus is often on the provision of services. It is precisely in this area of core competence that support is needed. Maturity models that assess an entire company overburden companies here in terms of the resources required. In addition, only a superficial level of detail is achieved through the broad view, which only insufficiently captures and considers the respective company specifics. Modular maturity models could be an attractive alternative here.

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4.2.3. Recommendations to maturity models / readiness models

Regarding the recommendations from the structured literature review regarding the use and development of MM/RM, the following table 5 delivers a summary of the recommendations.

Table 5. Recommendations to MMs/RMs

Recommendation	author
An iterative application of maturity models and ongoing improvements is recommended.	Jodlbauer & Schagerl, 2016
A targeted maturity level of the highest level (10 in this case) is not the goal, as investments should be aligned with the optimal use of resources (e.g., ROI) and maximum investments are not profitable.	Jodlbauer & Schagerl, 2016
Procedure for valid results: Initial workshop to clarify all basic questions --> followed by separate interviews with the individual departments --> final evaluation of the results in a final workshop.	Jodlbauer & Schagerl, 2016
Tools to support Industry 4.0 needs to be easy-to-handle, as the topic is already very complex.	Leyh et al., 2016
Questions in a questionnaire should be formulated in a positive tone, to decrease the effort the participant has to put in.	Li et al., 2017
The reduction of the number of questions in a questionnaire increases the rate of responds.	Li et al., 2017
By grouping questions and converting them into multiple-choice questions, the number of words and questions included in the original model is reduced considerably.	Li et al., 2017
The field of human is especially extensive and affects the entire company --> people of different divisions should ideally be included in the maturity assessment process.	Pessl et al., 2017
Define a roadmap for Industry 4.0 implementation is highly recommended --> strategical and technological perspective.	Ghobakhloo, 2018
A comprehensive strategic roadmap including the individual steps, timing, associated costs and resulting benefits must be carefully identified & planned to make the transition to Industry 4.0 tangible for SMEs.	Ghobakhloo, 2018
It is recommended that the focal firm uses the assessment results to share best practices and knowledge with its key partners, so a long-term and comprehensive roadmap can be implemented.	Bibby & Dehe, 2018
Different industries demand different weightings per dimension and maybe additional specific items. Therefore, an additional or adapted specific analysis is recommended.	Blatz et al., 2018
Time and resources can be saved when the correlations of the different dimension are considered in a systemic manner rather compared to an approach where the changes are implemented isolated.	Blatz et al., 2018
The interdimensional correlation between items shows that digitization is not a stepwise plan that can be executed dimension after dimension. It is complex and the regular check of the development of the digital maturity is strongly recommended, to measure progress and to become aware of change impacts.	Blatz et al., 2018
A MM for SMEs needs to take the direct leadership & more general employees (qualification & responsibility) into consideration.	Mittal et al., 2018
Successful corporate development in the direction of Industry 4.0 must take equal account of the three dimensions of technology, organization and personnel, including their respective interdependencies.	Leinweber et al., 2018
The general adaptability of MMs/RMs to the organizational structure of SMEs is essential. It should support an agile enterprise and enable rapid decision-making and adaptation processes in all parts of the company and across all business process areas.	Wiesner et al., 2018
A suitable maturity model should be simple to understand and implement, explain the overall idea of digitization and the associated concepts, and clarify uncertainties instead of creating new ones.	Wiesner et al., 2018
KPIs for evaluation in Industry 4.0 transformation process should also be low-level and not nested.	Cognet et al., 2019
The study works with KPIs instead of answers/questions or dimension/sub-dimensions ---> The KPIs needs to be explicit and not implicit to be simple in usage and later derive from the results.	Cognet et al., 2019
An open dialogue with the companies/participants is required to identify contextual factors that enable a tailored digital transformation roadmap with specific improvement recommendations.	Colli et al., 2019

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In order to avoid biases related to the corporate hierarchy, data collection workshops should be conducted with the main person in charge of each field (several sessions per field to be discussed).	Colli et al., 2019
Factors from sociological aspects are directly related to the maturity of smart manufacturing --> future MMs should take this into account and develop MMs with sociological and technological aspects.	Yue et al., 2019
Social aspect factors directly affect the maturity level of SM, while technical aspect factors indirectly keep enterprises at a high maturity level --> development of comprehensive MM/RM for SM should consider economic and technical aspect.	Yue et al., 2019
To avoid misunderstandings and false expectations, it is important to develop a dedicated Industry 4.0 strategy & align it with overall corporate strategy. A broad strategic approach is key, not focus only on technological aspects in isolated environments.	Hoyer et al., 2020
MMs need to be improved in terms of incorporating design principles to address all aspects of I4.0 and provide companies with a leadership tool that has a measurable impact on their business performance.	Dikhanbayeva et al., 2020
A suitable tool as a project guidance is necessary to assist the building of transformation capability.	Lin et al., 2020
A good diagnostic tool that traces current state & future state, along with the development of a roadmap, can make the understanding and feasibility of applying these models more attractive to organizations.	Ramos et al., 2020
It is recommended to have detailed descriptions of the several dimensions for better understanding of the participants and to make it easier to validate the correct maturity level for SMEs.	Rauch et al., 2020
SMEs have to rely on validated Industry 4.0 proceedings as they can't afford multiple project iterations.	Schmitt et al., 2020
No specific definition of "digital maturity" --> reference value indifferent and a subjective assessment by the reader --> main requirement: the precise definition of the terms used for Industry 4.0 maturity models.	Thordsen et al, 2020
The dimensions included in the design of a MM should include all the ones that are impacted by the transformation.	Zapata et al.,2020
MMs need to expand their scope of action to Industry 4.0 transformation is not only about operational excellence, but also about expanding the product and service portfolio by developing smart products.	Zapata et al.,2020

MMs/RMs are a suitable option for SMEs to get started with Industry 4.0, although they are fraught with imponderables, as many MM/RMs are designed more for MNEs. Therefore, the objectivity of the derived results should always be seen in context and questioned, as the models are not yet sufficiently validated. Furthermore, the subjective interpretation of users is a pitfall resulting from the danger of evaluating company-specific circumstances too positively or too negatively. A fact-neutral assessment formally oriented to standards and definitions has not yet been achieved, and SMEs therefore need a solid basic understanding of Industry 4.0 for interpretation. In addition, the complexity of the maturity models usually overwhelms SMEs when an entire company is to be assessed. Modular maturity models could be an attractive alternative here.

5. Conclusion, limitations and future work

The present structured LR shows that Industry 4.0 for SMEs is still at an early stage despite technological and organizational improvements. The criticisms / recommendations indicate that a structured and coordinated approach for different company sizes / industries and binding formulations are needed. Then MM/RM can lower the hurdles for implementation by structured questionnaires, categorization and derived roadmaps. There is a rich pool of these models (tables 4 & 5), but selecting the appropriate model is also a major challenge. It is also noticeable that the MM/RM studied do not have a high number of validations. This would be typical if a product has gained a high reputation through its application. It can therefore be argued that this level of quality has simply not yet been achieved. On a positive note, the view for MM/RM is broadening and, in addition to technical aspects (i.e., sensors, actuators & technologies) led by humans. Newer MM/RM therefore increasingly include social and socioeconomic aspects. This does justice to the basic idea of Industry 4.0, in which humans continue to play a central role.

A new/further development of MM/RM for the implementation of Industry 4.0 in SMEs is therefore necessary in order to take into account all the findings and recommendations listed above. In this context, consistency of definitions is one of the fundamentals to make the models more user-friendly and to create clarity. Limitations in this structured LR

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may result from the chosen search parameters (time period, search terms, etc.) and the chosen database, but are not of limiting scope for scientific consideration. The next step is the detailed analysis of all models found and, based on this, the design and development of an SME-specific MM that supports the readiness of SMEs for the introduction of Industry 4.0 or trains them in dealing with Industry 4.0.

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