Assessing the IT and Software Landscapes of Industry 4.0-Enterprises: The Maturity Model SIMMI 4.0

Christian Leyh[1(✉)], Thomas Schäffer[2], Katja Bley[1], and Sven Forstenhäusler[2]

[1] Technische Universität Dresden Chair of Information Systems, esp. IS in Manufacturing and Commerce, Helmholtzstr. 10, 01069 Dresden, Germany
{Christian.Leyh,Katja.Bley}@tu-dresden.de
[2] Faculty of Business Administration, University of Applied Sciences, Max-Planck-Str. 39, 74081 Heilbronn, Germany
Thomas.Schaeffer@hs-heilbronn.de, Sforsten@stud.hs-heilbronn.de

Abstract. The increasing digitalization of business and society leads to drastic changes within companies. Nearly all enterprises have to face enormous challenges when dealing with topics such as Industry 4.0/Industrial Internet. One of these challenges represents the realistic classification of the company's own IT infrastructure. In this paper we present a maturity model (SIMMI 4.0 – System Integration Maturity Model Industry 4.0) that enables a company to classify its IT system landscape with focus on Industry 4.0 requirements. SIMMI 4.0 consists of 5 stages. Each describes several characteristics of digitization, which allows a company to assess itself. Additionally, recommended activities are presented for each stage of digitization, which can enable a company to reach the next stage of maturity. Due to the large number of possible characteristics concerning Industry 4.0 and digitization, we also present several possible topics for future research to improve and refine the developed maturity model.

Keywords: Maturity model · Industry 4.0 · Industrial Internet · Digital transformation · Digitization

1 Motivation

One of the most important challenges that companies currently face is the digitization of business processes and of the enterprise itself. They have to join in global digital networking, improve automation of individual or even all business processes, and reengineer existing business models to gain momentum in digital innovation. Meanwhile, the progressive and steady digitization of society, with associated changes, has also arrived in the everyday life of enterprises. It has never been more important for enterprises to be able to rely on IT-enabled capabilities, as well as to count on a deep understanding of information technology in general and in digital innovation in particular. These changes and challenges are enormous and are no longer restricted solely

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to industry sectors, which depend on or have to use innovative technologies for creating and selling their products or services. Without a doubt, nearly all enterprises have to undergo an increasing digital transformation to remain competitive in global markets. The areas affected by these changes are diverse: e.g., the use of enterprise resource planning (ERP) or similar company-wide enterprise systems to achieve holistic support and planning of business activities throughout the company and across the company´s borders [1–4], or the increasing interconnectedness of classical horizontal value chains to a complex value network [1, 5]. Digitization offers many approaches for automating workflows, reducing transaction costs, and increasing flexibility in dealing with customers and business partners. In these efforts, the specific challenge for companies is to realize the increasing integration of virtual, digital programs with real objects or products in their everyday business in order to subsequently adapt, enhance, or optimize the processes [6].

For a while, trends such as Industry 4.0/Industrial Internet, Big Data, and Cloud Computing affected mainly large companies, especially since small- and medium-sized enterprises (SMEs) often judged those topics as too complex and expensive and partially classified them as not relevant. However, digitization is no longer limited to large companies and does not only concern separate functional areas such as the IT department. Rather, it takes place throughout the entire value chain of all companies [7]. The advantages are also relevant for SMEs (e.g., a profitable growth through new products, new services, and innovative business models). With digital technology, costs are reduced and the company can be more efficient in its daily business activities [8].

Realizing these advantages, SMEs open themselves for the complex topic of Industry 4.0 and try to reshape their business processes and business models in this direction by an increased usage of Information and Communication Technology (ICT). However, it is obvious that the increasing transformation of everyday business, in addition to the opportunities, is not without risks for existing business models. Such profound changes to the corporate structure require large investments and can lead to temporary shortfalls of individual departments during the restructuring process. However, this implementation seems inevitable regarding increasing national and international competition. For example, currently SMEs mainly use advanced ICT for handling production and business processes. E-mail and the internet as the main communication mediums are constantly increasing in importance; computerized programs specify production and enterprise systems support all kinds of daily business operations. Overall, together with this increasing digitalization of companies, the definitions of value-adding and supportive processes become vague, whereby the traditional supply chain of a company with its downstream processes develops into a holistic supply/value network.

To face up to this development the use of adequate ICT is essential. However, what is missing at this point is the companies' level of knowledge concerning their own digitization. A number of studies already exist applying to this topic (e.g., [9–12]). By using various interrogation techniques, the authors figure out which information and enterprise systems are used in business (especially in SMEs) and in what shape the IT-infrastructure of the company appears. There is, however, the question of how an IT landscape must be designed so that a company can "move" in the field of Industry 4.0.

Recognizing and evaluating what systems are needed, and in which way and for what purpose, still embodies a challenge for companies.

This is where the present paper comes in. As extended paper of Leyh et al. [13] we present a tool (a maturity model) that enables companies to classify their own provided IT system landscape in the needs of an Industry 4.0 system landscape. This results in the main research question for our research:

What should a maturity model look like to assess a company's IT system landscape in the context of Industry 4.0?

In order to answer this question the paper is composed of four sections. Following this motivation, Sect. 2 gives brief insight into the field of Industry 4.0, as well as in the field of existing maturity models, whereas Sect. 3 summarizes the development of our maturity model "SIMMI 4.0" (System Integration Maturity Model Industry 4.0). Sect. 4 represents the core of our paper. In this chapter, the components (dimensions and stages) of SIMMI 4.0 necessary to fulfill the requirements of an Industry 4.0 environment are described. The paper finishes with a short summary and an outlook for future research in this field.

2 Conceptual Background

As already mentioned in the motivation section, the topic "Industry 4.0" has gained more and more importance and has spread with all its diversity in enterprises. Industry 4.0, as the fourth stage of the industrial revolution is entitled, consists of an increasing digitization of products and systems, together with their interconnectedness. Thereby, the physical world is connected to the virtual world. The focus lies on an enhancement of the automation, flexibility, and individualization of the products, the production, and the connected business processes [14, 15].

The characteristics of Industry 4.0 are: e.g., horizontal integration across whole value networks, strong vertical integration within the company, and a digital transparency of the engineering across the entire value chain [14]. However, a universal definition for the term "Industry 4.0" does not exist. Despite this, from the aforementioned descriptions and further characteristics of Industry 4.0 we deduce a working definition as the foundation for our research:

Industry 4.0 describes the transition from centralized production towards one that is very flexible and self-controlled. Within this production the products and all affected systems, as well as all process steps of the engineering, are digitized and interconnected to share and pass information and to distribute this along the vertical and the horizontal value chains, and even beyond that in extensive value networks.

In addition to the organizational challenges, the question of the right business model, and the adjustments of the existing business models faced by companies that want to align themselves more towards Industry 4.0, the enterprise´s IT department is also confronted with an integration challenge of further/additional IT systems. Through the development of the last few years (especially in the field of digitization), the homogeneous IT system landscape of the 1990s and 2000s is now divided into smaller heterogeneous systems. This change results from the requirements used when companies want to foster activities in the field of Industry 4.0, since those requirements often cannot be covered by one "large, all-encompassing" IT system. From this point of view, the need arises that the companies must be able to classify their IT system landscape regarding Industry 4.0 requirements. They have to be able to analyze their landscapes to identify whether or not it is sufficient and provides a stable foundation for Industry 4.0 activities. A tool is needed for this purpose (for example, a maturity model) that enables the company to classify its IT system landscape and also the landscapes of its business partners.

Therefore, to get an insight in the existing literature regarding maturity models, here with a focus on Industry 4.0 and its requirements, we conducted a systematic literature review. This analysis was done in three steps:

- **Step 1:** Development of a classification scheme for systematically assessing and evaluating maturity models. Here, we oriented our scheme on the classification scheme of Wendler [16] and enhanced this scheme with further criteria since Wendler [16] evaluates the papers and not the maturity models described within them. In the Appendix our classification and its assessment is provided by conducting one example evaluation of the maturity model of Benguria and Santos [17].
- **Step 2:** Conducting the systematic literature review. We used the approach suggested by vom Brocke et al. [18] to identify relevant articles. In addition, we used the paper of Wendler [15], which provides a valuable overview of maturity model papers.
- **Step 3:** Classification, assessment, and evaluation of the identified papers and maturity models. The identified articles (53 papers focusing maturity models) were analyzed and classified according to the scheme in the Appendix. The list and classification of all analyzed papers, and therefore of the maturity models, will not be part of this article, but will be provided by the authors upon request.

The analysis of the identified articles and maturity showed that the models have an average of five stages and numerically very different dimension characteristics per stage. Furthermore, not all maturity models follow a concrete process model in their development, and most of them lack a thorough evaluation especially with regard to their usage in practice. Mostly, the identified papers represent an initial proposal of a model and somehow the development process is described more or less extensively.

Summing up the results of our literature review, it became evident that there are a couple of maturity models for classifying the IT system or software landscape of enterprises (e.g., LISI: [19]; OIMM: [17]; SIMM: [20]; SPICE: [21]). However, we could not identify a maturity model that deals with or that has an explicit focus on the requirements of Industry 4.0 in combination with the IT system landscape of an enterprise and of its partners in the value chain. However, some of the analyzed maturity models contain in part some related and relevant approaches, but these mostly do not cover the required functionality and content of a highly integrative and organization-wide digitization for the model-application in the field of Industry 4.0. Hence, in combination with the statements from the motivation section, the need to develop a more capable and matching maturity model for the context of Industry 4.0 is given.

3 Research Methodology – Development of SIMMI 4.0

Since Industry 4.0 is an enterprise-wide and even an inter-corporate topic, the IT system landscape should also have an inter-corporate nature by using the potential of current technologies and approaches. To take this into account, the development of SIMMI 4.0 follows a detailed development strategy (described below) and is thus based on the derivation or modification of existing maturity models. For this purpose we especially used maturity models that are related to the topic of IT system landscape, e.g., CMM(I) [22–24] and SOAMM [25]. Several components of those models were combined and adjusted according to the requirements of Industry 4.0.

In general, maturity models can be regarded as artifacts, and, therefore, the principles of design-oriented research are applicable. For example, the development of a maturity model generally follows, according to those principles, three phases: problem identification, designing the artifact, and evaluation of the artifact [26].

As a process model for developing maturity models, de Bruin et al. [27] developed a generic phase model based on the findings of the analysis of the development process of the Business Process Maturity Model (BPMM) and the Knowledge Management Capability Assessment (KMCA). They suggest six steps for this process model: scope, design, populate, test, deploy, and maintain.

Whereas, Becker et al. [26] apply the seven guidelines (1–Design as an Artifact; 2–Problem Relevance; 3–Design Evaluation; 4–Research Contributions; 5–Research Rigor; 6–Design as a Search Process; 7–Communication of Research) of the Design Science framework from Hevner et al. [28] for the development process of maturity models. They suggest eight phases for the development process: (1) problem definition; (2) comparison of existing maturity models; (3) defining the development strategy; (4) iterative maturity model development; (5) conceptual design for the transfer and evaluation of the maturity model; (6) implementation of transfer approaches; (7) conducting the evaluation; and, if necessary, (8) discarding the maturity model [26].

Therefore, due to the iterative procedure, the full-scale documentation guide of the development process also assesses the validity and reliability of the model for the scientific discourse of the process model of Becker et al. [26]. In addition, due to the already successfully developed maturity models following the process model (e.g. [29, 30]), we decided to follow this process model for the development of SIMMI 4.0 (System Integration Maturity Model Industry 4.0).

Following this process model, SIMMI 4.0 is currently in phase 4 (iterative maturity model development). We identified an existing problem enterprises face within the field of Industry 4.0 (phase 1), and we compared existing maturity models (phase 2) by conducting a systematic literature review (see Sects. 1 and 2). However, we cannot describe the development process of SIMMI 4.0 to a full extent within this paper. Therefore, this process is described in Leyh et al. [31].

In phase 4, SIMMI 4.0 is in its first iteration. The findings from the analysis of the literature about the general structure of maturity models were combined with the requirements for an IT system landscape of a company that wants to operate entirely in the context of Industry 4.0. Thus, in the following section we present SIMMI 4.0 in detail to provide an understanding of how a company could/should evaluate its IT system landscape with focus on Industry 4.0.

4 SIMMI 4.0 – System Integration Maturity Model Industry 4.0

As a starting point for model development, a further literature analysis was conducted. Contrary to the literature analysis of Sect. 2, the aim of this analysis was to gain an understanding about the existing level of knowledge about Industry 4.0, and, therefore, to deduce the essential requirements for IT systems in the context of Industry 4.0. Several databases (e.g., EBSCO, ScienceDirect, SpringerLink, and Google Scholar) were searched using the following terms and combinations of these terms: Information systems, Industry 4.0, Maturity models, Integration, Digitization, Internet of things and services, Cyber-physical systems, Value networks, IT systems, Enterprise systems, and Business information systems. Some of the resulting requirements from this literature analysis are presented as follows.

4.1 Requirements for IT-Systems in the Context of Industry 4.0

In their final report about Industry 4.0, Kagermann et al. [14] highlighted three key requirements fostered by Industry 4.0 and thus should be supported by the enterprise application system landscape:

Vertical Integration along the hierarchical levels of a company: While the different enterprise systems support their own tasks very well, the data of the respective systems, such as Enterprise Resource Planning (ERP) systems, Supply Chain Management (SCM) systems, Management Information Systems (MIS), Product Life cycle Management (PLM) systems, etc., is often stored in separate databases (sometimes data interfaces are provided) and partly stored in different formats. This sub-optimal level of integration must be improved for implementing Industry 4.0 business processes and activities.

Horizontal Integration across value networks: For the implementation and use of different enterprise systems, failures and leakages throughout the flow of information must be avoided. In fact, the information must be accessible and useable at the right time in the right "place" along the entire supply chain and therefore for all business partners. Furthermore, the exchange of such information flows must be (completely) automatized.

Digital Continuity of engineering: This means supporting a product's engineering consistently and continuously along the entire supply chain by using adequate and appropriate enterprise systems and includes the production system development process as well.

Also, stemming from the literature review (especially from analyzed study results), cross-sectional technologies were identifiable as an important part of the enterprise systems. These technologies are defined below and their relevance to Industry 4.0 will be explained:

Service-Oriented Architecture: For example, the project "Platform Industry 4.0" has published a whitepaper that names the development of a reference architecture based on a Service-oriented architecture (SOA) as an important prerequisite for the implementation of Industry 4.0 [32].

Cloud Computing: Industry 4.0 not only leads to a digitization of separate production facilities, but also that of the enterprise's information technology at the production plant(s) as well as all companies digitally interconnected along the supply chain. Considering cloud computing, these aspects are provided as different services; therefore, this could help enterprises operate in the field of Industry 4.0 effectively and efficiently.

Information Aggregation and Processing: In this context, aggregation of information implies that data can be easily identified from various integrated enterprise systems through different ways of treatment, such as clustering, filtering, and correlation. In a next step, this data is made available to every user or machine that needs it. This illustrates not only that the data of the production floor/of the production systems (e.g., various interconnected machines, (semi-) products, sensors etc.) is aggregated and transferred towards the company's higher levels and enterprise systems (e.g., ERP systems, SCM systems), but also that the data needs to be transferred in the opposite direction to the production floor [33].

IT Security: In Industry 4.0, the company will be connected with/to the internet not just at an operational or higher level. As part of the Internet of things and services, the production level/production floor, maybe even the control level of several machines themselves, as well as all levels up to the strategic level of companies will be connected through a continuous link to the internet. For this reason, IT security will be a major challenge for establishing different kinds of IT systems. Here, IT security is defined as adequate protection of all information available in form of electronic data. In addition, it must be ensured that the IT systems themselves and their services are available at all times for the users and work properly [34, 35].

4.2 Components of SIMMI 4.0

Depending on its aims and strategic positions as well as on its arrangements in terms of Industry 4.0, not every company needs to fully implement all the dimensions of SIMMI 4.0. There are several gradations per dimension, which in turn result in different stages within the maturity model. These dimensions can have different characteristics in terms of scope and intensity for each company. Therefore, Table 2 in the Appendix gives a summary of our proposal for SIMMI 4.0. In the following chapters, the dimensions and stages of SIMMI 4.0 are described in detail.

Dimensions of SIMMI 4.0

Several dimensions of the development of SIMMI 4.0 are deduced from the requirements from our literature analysis. With these dimensions, SIMMI 4.0 can enable a company to assess its IT system landscape.

Dimension – Vertical Integration: This dimension focuses on the components of the lowest level of an enterprise, where different physical things ((semi-) products, machines, etc.) need to exchange information throughout the level itself and with the levels above. The most important criterion here is that this exchange is possible in both directions.

Dimension – Horizontal Integration: Industry 4.0 requires horizontal integration across the different value networks. Accordingly, an essential criterion has emerged from the requirements above. An automated and integrated information flow is necessary along the horizontal enterprise level as well as beyond the enterprise borders. Without this information flow, a business-wide value network is not realizable, meaning that the various enterprise systems of the different partners in the supply chain and in the value networks require interoperability at the data level. Therefore, a continuous and consistent information flow is needed [36, 37].

Dimension – Digital Product Development: For the engineering's digital continuity it is especially important that each process step is represented digitally. For this purpose, at least one enterprise system should be integrated into each respective process step. In addition, the resulting data and information of each step must be forwarded to the next and previous step/enterprise system.

Dimension – Cross-Sectional Technology Criteria: This dimension focuses on assessing the extent to which technologies are used across all different fields of Industry 4.0. Based on the requirements, the respective fields are: Service-oriented architecture, Cloud computing, Big Data, and IT Security. In addition, the level of support that enterprise systems can provide for these fields should be evaluated in this dimension.

Stages of SIMMI 4.0

SIMMI 4.0 is divided into five stages. This five-stage division is justified by the fact that in the middle of this stage-model, in the third stage, the implementation of an intelligent factory (Smart factory) is completed. This foundation for Industry 4.0 should be and must be implemented in each company before stable, robust, and versatile value networks can be realized. By implementing an intelligent factory, a company can gain operating experience and test technology before the company and its systems are connected to other companies [36]. Key activities for each stage, which must be conducted in order to be able to achieve a higher stage, are briefly specified.

Stage 1 – Basic Digitization Level: The company has not addressed Industry 4.0. Requirements are not or only partially met.

The enterprise systems along the enterprise's value chain support only their respective fields of activity. When integration is achieved, it is with specially implemented and complex interfaces. In addition, the processes are not or are only partially digitized. Product prototypes are designed in a costly way because of product development activities are not digitized. The company does not pursue service-oriented and cloud-based approaches.

The data of the enterprise systems are aggregated only for strategic decisions. In addition, the confidentiality of the data is not provided. The company's data is not protected against industrial espionage for example, incurring enormous damage annually. Anytime and continuous availability of data is not ensured. Sometimes, users cannot receive the data when they request it or access is not provided.

Activities:

- Start of engagement with focus on Industry 4.0
- First explorations of service-oriented approaches

Stage 2 – Cross-Departmental Digitization: The company is actively engaged with Industry 4.0 topics. Digitization has been implemented across departments, and the first Industry 4.0 requirements have been implemented throughout the company.

Information can be (partially) exchanged automatically among different departments and business areas. This level of integration no longer contains data islands within the company. In addition, several production plants are connected but instead through cloud solutions they are connected through the exchange of information in other ways (paper-based, email, FTP, etc.).

Production and product development is supported by several enterprise systems. However, data and information exchange is not automatized. Therefore, the previous and following steps are not optimized. The company starts to implement an SOA. Legacy systems are broken down, and their functionalities are encapsulated into services. New systems are implemented directly following the SOA principles. Thus, initial processes can be built as services. In addition, an enterprise service bus (ESB) is implemented to replace enterprise application integration principles and to enable direct connection between new systems.

Activities:

- Implementing an SOA
- Achieving cross-departmental integration
- First approaches for an IT security model
- First developments of mobile applications

Stage 3 – Horizontal and Vertical Digitization: The company is horizontally and vertically digitized. The requirements of Industry 4.0 have been implemented within the company, and information flows have been automated. The product development is consistently supported by enterprise systems. Information from the respective process steps can be forwarded to the next or previous process step.

The company has established an SOA. All the functionalities of the integrated systems are provided as services. The (semi-) products are part of this SOA and provide services themselves.

To exchange information within the enterprise, cloud principles are applied. Services are available company-wide and can be accessed anywhere. Employees are able to retrieve information everywhere through mobile devices. In addition, machines and (semi-) products are displayed on the mobile devices as soon as they come into the device's range. With this feature, the devices can display additional information about the machines (e.g., current processing step, maintenance status, etc.).

Various data from the production plants will be aggregated and processed together. Using this data and information gained from production, production itself can be optimized in real time and can be adapted to prevailing or changing conditions when necessary.

IT security is increased through the use of an advanced security model. Access to data is continuously protected, and data is transmitted in an encrypted state within the enterprise. The data's confidentiality, availability, and integrity are completely guaranteed.

Activities:

- Connection with other companies to build value networks
- Development of a cloud-based platform to offer services across the company borders

Stage 4 – Full Digitization: The company has been completely digitized, even beyond corporate borders, and integrated into value networks. Industry 4.0 approaches are actively followed and anchored within the corporate strategy.

Consequently, the level of integration can be described as enterprise-wide and cross-corporate horizontal and vertical integration. In order to optimize processes, the product development steps automatically pass information to previous and following production steps.

The company has established a service-oriented and cloud-based platform that offers services in the value network in order to exchange information along the supply chain in real time. Machines can be maintained globally, regardless of their location (in terms of their software). Data is aggregated and processed company-wide as well as provided via entire value networks. The production floor in general is at a highly optimized level.

In addition to enterprise-wide data encryption, encryption is also used within the value networks. Users can access data anywhere by using established authentication measures.

Activities:

- Beginning collaborations with companies within the value networks for end-to-end solutions and the optimization of information flows

Stage 5 – Optimized Full Digitization: The company is a showcase for Industry 4.0 activities. It collaborates strongly with its business partners and therefore optimizes its value networks. Through these collaborations, new business models and new end-to-end solutions are developed and enabled. During this development process each step inside and outside the company is digitized.

Within the value networks physical value and information flows can also be represented digitally, so the entire added value can be simulated in real time. Thus, it is possible to automatically perform necessary adjustments for all companies of the value network.

Furthermore, the IT security adjusts promptly to new risks. Occurring security problems are immediately solved. Encryption is optimized in cooperation with the partners the along the value networks.

5 Summary and Future Aspects

The aim of this paper was to develop a maturity model for the classification of a company's IT system landscape in the context of the Industry 4.0 requirements. Through a systematic literature review, we could demonstrate that no maturity model currently exists that meets the needs of Industry 4.0 in terms of a company-wide and even a cross-corporate IT system landscape. However, due to the drastic changes produced by the digitalization of businesses and society itself, it becomes necessary for enterprises to assess their IT system landscape in a realistic way. Therefore, an easy-to-handle tool could provide adequate support for assessment.

With this in mind, we designed a new maturity model (SIMMI 4.0 – System Integration Maturity Model Industry 4.0) for assessing the readiness of a company's IT system landscape in terms of Industry 4.0. Therefore, we derived several Industry 4.0 requirements based on a second literature review and combined them with the results of our first literature review with a focus on existing maturity models. In general, our design process was conducted with reference to suggested procedure model of Becker et al. [26]. However, this design process is not described in detail in this paper but can be found in Leyh et al. [31].

Therefore, this paper presents the first version of our maturity model SIMMI 4.0. According to the procedure model of Becker et al. [26], the development of SIMMI 4.0 is currently in phase 4 (iterative model development). Thus, the model's development is not yet fully complete. The next iterations in phase 4 include:

- Conducting several expert interviews and model adjustments based on the interviews if necessary (2nd iteration);
- Group interviews with companies to test the model's practicability (3rd iteration).

After phase 4 is completed, evaluation of the maturity model will follow. These steps should be based on the concrete application of the model within several companies. The resulting design decisions based on the iteration steps, the transfer and evaluation in terms of the model's dimensions and stages, more detailed evaluation steps, and the model's scientific as well as practical contributions will be addressed in subsequent papers.

Beyond the development of SIMMI 4.0 (here primarily based on the literature review in Sect. 2, the comparison of existing maturity models), we identified additional links and needs for further research For example, some maturity models already exist for the field of Industry 4.0 that deal with organizational aspects [38] or system-specific aspects in detail [39]. A mapping of these maturity models would be necessary to combine their different points of view. For example, different maturity level assignments and dimensions between these models should be developed to enable companies to fully classify themselves in terms of Industry 4.0 requirements in all levels of their enterprise. With this work, companies would be able to determine their overall maturity in the field of Industry 4.0.

A further aspect to investigate in the future is the data quality within various enterprise systems along the supply chain. Since companies in an Industry 4.0 environment must exchange data in large amounts and on an automated basis, a certain data quality is necessary to ensure efficient company-wide and cross-corporate business processes. Therefore, those companies should implement adequate master data management and data quality management. On this topic, two questions arise: (1) What design elements and components should be part of master data management and data quality management in the context of Industry 4.0? (2) How can master data management be integrated in maturity models addressing the IT systems landscape of Industry 4.0 companies? We will address those two questions in further research projects.

To conclude this contribution, some limitations must be recognized. Currently, SIMMI 4.0 has not been evaluated or tested. It is a maturity model that was derived from the literature by combining aspects of IT-related maturity models with Industry 4.0 requirements. In this respect, the development process of SIMMI 4.0 must continue. In the next iteration steps, we will clarify and review the model's components based on expert and company assessment. Additionally, SIMMI 4.0 must prove its practicability and usefulness in an enterprise environment. Therefore, we will address both aspects of the model's limitations in our research project's future steps focusing the field of Industry 4.0.

Appendix

Tables 1 and 2.

Table 1. Example of a categorized maturity model (see [17]) according to our classification scheme

#	Attribute	Description
A1	**Paper title**	**SME Maturity, Requirement for Interoperability**
A2	**Year of publication**	2008
A3	**Country**	Spain
A4	**Summary**	The paper presents an implementation strategy for interoperability in the SME context (small and medium-sized enterprises). The strategy consists of: (a) an improvement cycle for establishing and for ensuring an interoperable state; (b) a maturity model for the classification of interoperability based on best practices; (c) an evaluation method to measure interoperability.

(*continued*)

Table 1. (*continued*)

#	Attribute	Description
A5	**Name of the maturity model**	No name specified
A6	**Industry sector/Field of application**	Spanning various classes of business
A7	**Company size**	Small and medium-sized enterprises (SMEs) → up to 250 employees and up to 50 million Euro turnaround per year
A8	**Artifacts**	Improvement cycle, Interoperability maturity model, Assessment method
A9	**Stages of maturity**	5 Stages: (1) Initial; (2) Performed; (3) Modeled; (4) Integrated; (5) Interoperable
A10	**Relevance and definition of the problem**	Development of a practicable and useable maturity model for SMEs
A11	**Comparison of existing maturity models**	• Capability Maturity Model Integration (CMMI); • Software Process Improvement and Capability Determination (SPICE); • Service-Oriented Architecture Maturity Model (SOA MM); Extended Enterprise Architecture Maturity Model; • Organizational Interoperability Maturity Model; • Levels of Information Systems Interoperability; • European Interoperability Framework; • Malcolm Baldridge National Quality Award (MBNQA); • European Foundation for Quality Management (EFQM); • ISO 9000; • Six Sigma
A12	**Defining the development strategy**	Combining multiple models to one maturity model
A13	**Iterative maturity model development**	One improvement cycle was performed
A14	**Evaluation**	An evaluation was conducted as case study within a medium-sized door manufacturer. Objectives of the case study: Testing the maturity model, its application and its classification approach, especially with an SME focus Getting know to interoperability limits regarding IT systems, technical aspects and organizational issues between customers and suppliers
A15	**Further research needs**	No information provided

Table 2. Overview of SIMMI 4.0

Dimension vertical integration	Dimension horizontal integration	Dimension digital product development	Dimension cross-sectional technology criteria
Stage 5 – Optimized full digitization The company is a showcase for Industry 4.0 activities. It collaborates strongly with its business partners and therefore optimizes its value networks			
Continuous cross-corporate integration that is constantly optimized	Continuous cross-corporate integration and collaboration in value networks	Product development is processed digitally inside and outside the company (digitized end-to-end solution)	Simulation and optimization of value and information flows in real-time within the value network. IT security adjusts promptly to new risks. Occurring security problems are immediately solved. Encryption is optimized along the value networks
Stage 4 – Full digitization The company is completely digitized even beyond corporate borders and integrated into value networks. Industry 4.0 approaches are actively followed and anchored within the corporate strategy			
Continuous cross-corporate integration	Continuous cross-corporate integration in value networks	Product development information are digitally forwarded	Service-oriented cloud-based platform. Services are offered for the partners in the value networks. Information and data are exchanged in real-time along the supply chain. Optimization of the entire production through Big Data solutions. Access to data is protected. Cross-corporate encryption of data and authentication for global access
Stage 3 – Horizontal and vertical digitization The company is horizontally and vertically digitized. Requirements of Industry 4.0 have been implemented within the company, and information flows have been automated			
Complete internal/enterprise-wide integration of all enterprise systems and machines	Complete internal/enterprise-wide integration of all enterprise systems and machines	Product development is continuously digitally supported	SOA has been established. All functions are provided as services. (Semi-) products and their functionalities are available as services. To exchange information within the enterprise, cloud principles are applied. Production is adjusted and optimized in real-time. IT security is increased through the use of an advanced security model. Access to data is continuously protected, and data is transmitted in an encrypted state within the enterprise

(*continued*)

Table 2. (*continued*)

Dimension vertical integration	Dimension horizontal integration	Dimension digital product development	Dimension cross-sectional technology criteria
Stage 2 – Cross-departmental digitization The company is actively engaged with Industry 4.0 topics. Digitization is implemented across departments and first Industry 4.0 requirements are implemented throughout the company			
Cross-departmental integration	Cross-departmental integration	Production and product development is supported by several enterprise systems. Data and information exchange is not automatized	Implementation of first services (SOA with an enterprise service bus (ESB)). First experience with Big Data and its applications. Development of the first IT security models
Stage 1 – Basic digitization level The company has not addressed Industry 4.0. Requirements are not or only partially met			
Integration of enterprise systems only departmental-specific. The enterprise systems along the enterprise's value chain support only their respective fields of activity	Integration of enterprise systems only departmental-specific. The enterprise systems along the enterprise's value chain support only their respective fields of activity	Product development is not digitally supported	No service-oriented or cloud-based approaches. Data and information flows are not used for product improvement/optimization. Confidentiality, availability and integrity of the data are not guaranteed

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