Toward the Development of a Maturity Model for Digitalization within the Manufacturing Industry's Supply Chain

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Abstract

The aim of this paper is the scientific development of a maturity model concerning the digital transformation of companies within the manufacturing industry's supply chain. The rather "broad" and dispersed "mega-trend" of digitalization is expected to play an increasingly important role for companies as well as for the (digital) supply chain of the future. Such a model comprises the objective of addressing fundamental components, complementary innovations and relevant terminologies, like smart products, Cyber-Physical Systems (CPS) and Big Data Analytics. Scientific rigor is achieved through conducting grounded theory research and in-depth interviews as methods of data collection and evaluation. Furthermore, relevant aspects concerning the development and construction of maturity models are discussed, before a suitable and scientifically elaborated maturity model concerning digitalization emerges from the course of investigation and its value for economic practice as well as for the scientific community is specified.

1. Introduction

Recent developments concerning digitalization are expected to play an increasingly significant role in the management and design of global supply chains. The shift of value from physical artefacts to "smart" products and the data they are creating poses particular problems especially to companies actively involved in production and logistics systems – or more general in value-adding activities. The revolution of economic products, services and processes right up to new eras of competition, the destruction of established structures and the redefinition of industry boundaries [27] will therefore be of exceptional impact for the manufacturing industry and its business models. In this context, the implementation of smart products and of Cyber-Physical Systems (CPS) as the technical foundation of the Internet of Things (IoT), in combination with other "mega-trends" of digitalization [17], are expected to shape the (digital) supply chain of the future [5]. The rather disruptive process concerning the transformation of companies into their digitalized counterparts constitutes an element of uncertainty and difficulty for many decision makers. Therefore, appropriate steps have to be taken in order to make this process more visible and transparent. At this point, we see a significant research gap, which we are intending to close through the implementation of an auxiliary maturity model. Such models are most suitable for dealing with complex, multi-faceted phenomena, enable the depiction of typical and potential evolution paths towards a desired state and furthermore involve a systematical documentation [28]. Maturity within the underlying context would therefore refer to the state of an organization in which it is perfectly capable of achieving its objectives [1] and of thereby mastering the various challenges of digital transformation. A perfectly "mature" company would thus be one, which successfully underwent the transformation process introduced within this paper.

Recent history brought up several maturity models mainly introduced by research societies, government agencies, interest groups, or consulting companies. These practice-related approaches provide suitable "quick" insights into the field, but usually lack a measure of scientific resilience and reliability, especially with regard to the thorough documentation of the development process. Furthermore, many of these "indices" or "indexes" do only address partial aspects of the overall meta-context of digitalization or do have an industry-branch-specific scope. They do thereby fall short of providing a complete overview over the respective process of digital transformation. Until the current state of research, the existence of a suitable maturity model addressing the "full" spectrum of digitalization within the manufacturing industry, using well-established and empirical grounded methodological procedures for its development and

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furthermore providing a sufficient amount of scientific transparency and documentation, has to be negated.

Starting from the identified research gap and the discussion of "shortcomings" regarding already existing maturity models, our central research question is *„How can the process of digital transformation be scientifically depicted and ascertained in case of the manufacturing industry's supply chain?"* Considering the fact that maturity models are usually generated and tested by qualitative approaches and do furthermore contain input from experienced practitioners [9], we relied on in-depth interviews as the core method of data collection. As evaluation method, we conducted a grounded theory approach, which constitutes an appropriate method for exploring the research question in a "fresh field", where no deep exploration – in the sense of scientific research and literature addressing digitalization maturity models – took place to date.

In order to address the central research question, this paper is structured as follows. Chapter two gives a brief introduction of related work concerning smart products, CPS and digitalization with special emphasis on the manufacturing industry's supply chain. The third chapter specifies the methodological background with regard to research design and data collection. Chapter four starts with a description of the process regarding the construction of the underlying maturity model and subsequently introduces the model itself. Finally, the fifth chapter discusses the results and limitations of our paper and identifies possible implications for further research.

2. Related work of smart products, Cyber-Physical Systems and digitalization

The concept of smart products and CPS will be of fundamental importance when it comes down to digital transformation and to shaping the (digital) supply chain of the future. According to [27], products are becoming more and more complex systems combining hardware, sensors, data storage, microprocessors, software and connectivity in multiple ways and have "unleashed" new eras of competition by reshaping industry boundaries, or by simply creating new ones [27]. Speaking of such smart products, a rather generic approach seems to gain increasing recognition within economic practice. However, when taking a stronger scientific perspective, the term CPS comes to the fore. Following [16]'s approach, such systems can be defined as networked embedded systems integrated into physical objects that have the capability to process information and data and to interact with the environment. They monitor, automate and control processes of the physical world via sensors, microprocessors and, if needed, actuators. CPS integrate the obtained data into the virtual world of information and distinguish themselves by a deterministic behavior, a high level of adaptability and by mastering complex data structures [16]. Both terms are largely congruent and can be used interchangeably in the majority of cases. Nevertheless, certain nuances should be distinguished: A smart product usually emphasizes some kind of final product, while a CPS can be any given physical object becoming "smart" through the embeddedness of microelectronics [16], which appears to be more suitable especially for industrial contexts. In that case, the term Cyber-Physical Production Systems (CPPS) occurs as well, as long as production machinery or other capital assets are subject to such kinds of electrification [38][39].

CPS are the fundamental concept realizing the IoT by transforming physical objects into their smart counterparts. Proceeding one-step further, the concept of the vertical integration of information and material flows [8] constitutes only one cornerstone within the field of digitalization. Furthermore, the interaction with the accompanying concepts of mobile and cloud computing, digital social networks and Big Data Analytics gains central relevance [17]. From a scientific perspective, all these different concepts can be regarded as complementary innovations to each another in the sense of a superordinate research framework or reference model, as proposed by [17]. By closely converging together and simultaneously reaching their maturity at short intervals, they are now forming the new meta-context of digitalization.

Within the underlying research project, digitalization is understood as "the transformation of socio-technical structures that were previously mediated by non-digital artifacts or relationships into ones that are mediated by digitized artifacts and relationships" [41]. By following this definition, it goes beyond the technical process of encoding analog data or information and of converting it into a digital format, frequently referred to as "digitization", and emphasizes the utilization of Information and Communication Technology (ICT) by organizations, companies or the society as a whole. The manufacturing industry's supply chain can in this context be determined as a network of interdependent organizations related to the physical transformation of materials, substances, or components into new products, working together with the target of controlling, managing and improving material and information flows from suppliers to end users [5][35]. With respect to the digital transformation of companies involved in these activities, it becomes of interest how a digital or digitalized enterprise might look like from a general perspective, as more and more business processes, products and even business models are transformed by digitized information. According to [14], a digital enterprise is characterized by "the application of Information and Communication Technologies (ICT) […] for the integration of activities in different functional areas as well as the so-called extended enterprise or partnering firms in the supply chain" [14]. In such an extended enterprise, where collaborative relationships between key supply chain members characterized by trust and a shared vision of gaining competitive advantage are paramount [5][32], data and information gain particular importance. This is among others due to the fact, that the "conventional" lean philosophy reaches its boundaries within many supply chains. Thereby, companies and their supply chain partners should shift towards more agile and flexible processes and structures [5][14]. This in turn requires a new quality and granularity of data and information, which again is facilitated by ICT-utilization [5]. Nevertheless, the core principles of lean production, in the sense of reducing lead times, inventory, bottlenecks and non-value-adding processes based on the application of a well-elaborated set of core-principles, tools and concepts [23], remain the basic prerequisite for the subsequent developments described in this paper. Within the (digital) supply chain of the future, perceptions from data and information, in the sense of Big Data Analytics [7], will no longer focus solely on visibility and transparency aspects but also on the creation of additional customer value. This development tempted leading analysts to the implication, that information in this context is the "oil" or even the currency of the 21st century. A company, which is completely aware of these developments, draws the right conclusions out of them and unrestrictedly takes the right and necessary measures, can afterwards be considered as a "data-driven enterprise".

3. Research design and data collection

With respect to the structured and strictly scientific development of a maturity model depicting the process of digital transformation within the manufacturing industry, we decided to pursue a qualitative approach by following the ideas of grounded theory research [10][11][33]. This mature methodology is designed to develop "theory" – understood as the "explanation" of a complex phenomenon – based on systematically collected data from qualitative sources. With respect to the data collection method, we conducted in-depth interviews [31], which are predominantly utilized as the main source of data within the framework of grounded theory research [21][29].

During our research project, we followed the "original" methodological approach of [10], including the adaptions and advancements introduced by [33]. This post-positivist approach uses "a systematic set of procedures to develop an inductively derived grounded theory about a phenomenon" [33] and includes a strict and complex process of systematic ("closed") coding [12]. This procedure occurs sequentially due to the fact, that grounded theory research is conducted iteratively, demanding a simultaneous analysis and collection of data, setting both in a reciprocal relationship [33][34]. Thereby, a theory evolves as a continuous interplay between data collection and analysis during the research process itself [12].

The concept of constant comparative analysis describes the analytical procedure of jointly converting relevant data into categories and their analysis by using explicit coding and analytical procedures and thereby generating theory more systematically [10]. Theoretical Sensitivity refers to a personal capability of a researcher focusing on the awareness towards the several nuances of relevant data enabling him or her to develop and render theory of a high quality [11][33]. Theoretical Sampling in a next step depicts the process of data collection for generating theory through the joint collection, coding and analysis of data wherein the sampling of the sources for additional data takes place based on already elaborated concepts of proven relevance to the evolving theory. Theoretical Saturation in turn is reached, when no additional data of relevance can be found and the relationships between the different categories are well established and validated [10][33]. This is achieved through remaining within the observed field until no new evidence emerges [13]. Finally, coding represents the process of breaking down, conceptualizing and rearranging data. It constitutes the central process within grounded theory research and it is composed of open, axial and selective coding [33].

While following the idea of multiple data collection and analysis iterations, we conducted interviews with 14 relevant actors from 12 different companies, involved into the supply chain of the German manufacturing industry. In order to create a sufficient database, we combined the concept of theoretical sampling with a purposeful sampling approach. Such a strategy allowed us to avoid selecting informants solely with respect to their potential theoretical contribution to already emerging concepts [24] and to putting additional emphasis on those promising information-rich discussions about issues of central importance to the purpose of our investigation [25]. With that in mind, we selected informants from companies not only out of different sectors of the manufacturing industry, but also with regard to their diversity in case of company size, specialization, value creation stage and their "expected" level of maturity regarding digital transformation. Within the respective company, potential participants were chosen following the key informant approach, focusing on such informants, which are most suitable to provide relevant insights due to their special/specialized knowledge [26]. We thus tried to acquire senior experts, responsible for or at least involved in addressing different aspects of digitalization within their company. This procedure goes in line with the common perception, that a typical maturity model is composed out of existing impressions from "good" and common practice and mainly generated from experience [9]. Table 1 gives a brief overview of the participants, including their job title and their company's industry sector, value creation stage and core product or service.

The inquiry period lasted from June 2015 until May 2016. This constitutes a rather long timeframe, which is on the one hand due to the limited temporal availability of potential participants, but enables on the other hand a thorough conduction of the iterative and thereby time-consuming process of reciprocal data collection and analysis. The number of interviews until theoretical saturation was reached resides within the common numerical "limits" of a grounded theory study [12][29] and furthermore appears to be sufficient for theory/model development. Interviews were conducted in the native language of the informant, were held either at the office of the participant or by phone and lasted between 60 and 120 minutes. They were audio-recorded [29] and later on transcribed by an uninvolved typist [20]. This avoided on the one hand potential distractions through the investigator taking notes and ensured the capability of directing the conversation, and on the other hand prevented biases through selective note taking and unintended familiarity with the data during transcription. As the interviews were conducted in the native language of the informant, we had to translate the results for the purpose of this paper. Furthermore, a complete anonymization became necessary in order to provide the essential confidentiality and secrecy to the participant's identity and their company's unique and competition-relevant knowledge [40].

The interviews were executed by at least one author of this paper, who obtained their sensitivity through the reading of literature as well as through professional and personal experience, which was in addition subject to further development during the research process [33]. Each interview started with a short, target-oriented introduction into the topic of digital transformation with special emphasis on the different mega-trends of digitalization. In this context, the participant was also questioned on his/her own understanding of the term digitalization and a brief discussion was held. Subsequently, the research project itself was illustrated and the following four open, non-directive questions were proposed:

- How would you describe the phenomenon "digitalization" from your company's perspective and when would you consider the state of being "digitalized" as achieved?
- How and to what extent did your company already get "in touch" with the process of digital transformation?

Table 1. Interview sample

Company/ Participant	Company characteristics/ Job Title
Company A	Energy sector, 2nd tier supplier, tap changers for transformers
Participant A	Head of Production
Company B	Automotive and industrial sector, 1st tier supplier, rolling and plain bearings
Participant B	Executive Assistant to Board of Directors
Company C	Automotive sector, 1st tier supplier, automotive supply parts
Participant C1	Head of Solution and Software Services
Participant C2	Commercial Director at one of the company's lead factories
Company D	Transportation sector, 3PL, global integrated logistics services
Participant D	Vice President Innovation and Trend Research
Company E	Transportation sector, 3PL, freight forwarding and accompanying services
Participant E	Senior Vice President Innovation
Company F	Energy and industrial sector, OEM, mechanical engineering and industrial services
Participant F	Chief Expert Software
Company G	IT sector, IT service provider, software solutions for process integration in logistics
Participant G	Head of Business Development
Company H	Air transportation sector, 3PL, global integrated logistics services
Participant H	Head of Innovation Management
Company I	IT sector, IT service provider, commercial and industrial IT solutions
Participant I1	Member of the Executive Board
Participant I2	Head of the Division software-based project solutions in manufacturing
Company J	IT sector, IT service provider, enterprise application software
Participant J	Vice President, Head of Internet of Things
Company K	U.S. division of Company F
Participant K	Head of the company's international Internet of Things Research Group
Company L	Mechanical engineering, OEM, industrial edgers and extruders
Participant L	Member of the Executive Board

- How would you describe the particular nuances, in the sense of development stages, within that digitalization process?
- How would you measure the advancement of your company alongside the process of digital transformation?

Those “grand-tour questions” [20] were introduced gradually resulting in an open and interactive discussion in the sense of a “guided conversation” [18]. This conversation was extended and deepened using planned prompts [20][29], consistent with the already existing constructs (as they evolved during the prior research process) in order to encourage further discussion on these aspects. In addition, floating prompts (probes) enabled the investigator of guiding the informant towards detailing key terms in an unobtrusive and spontaneous way [20]. The interview as a whole was supported by a corresponding interview-guide [4][18][33], leading the investigator through the moderation of the interview. This accompanying file especially contained the opening questions, planned as well as floating prompts, and was subject to improvements and enhancements in the follow-up of each data collection period.

Systematic coding, in the sense of breaking down, conceptualizing and rearranging the data derived, was executed by both authors and supported by the use of the pertinent software tool MaxQDA [22]. During this process, we identified key concepts from the repetitive line-by-line reading of the verbatim interview-transcripts (open coding). In a next step, we collapsed and aggregated them into more abstract, conceptional categories (axial coding). In order to avoid interpretational biases, we operated independently from another during serial and axial coding. If there were any inconsistences during this process, the aspect was set under further review and discussion until a consensus was reached. Finally, we achieved a higher meaning by identifying, grouping and summarizing core categories, by investigating their relationships among each other, and thus by integrating them into the evolving maturity model (selective coding). Notably the last step constituted a certain challenge, as the research process at this point leaves the transcribed data behind and requires the integration of respective categories in order to form the desired model [33].

4. Development of a digitalization maturity model for the manufacturing industry

Maturity can be described as a state in which an organization is in perfect condition to achieve its objectives [1]. According to [9], this condition has to be reached through the development of the object under observation over several intermediate states. The visualization of such a process constitutes the overall target of a maturity model, understood as “a construction-based model which consists of an anticipated, limited development path, separated into stages with defined characteristics and dimensions. It has one or more objectives related to the stage evaluation, gap identification and transformation.” [15] Such a model therefore constitute a suitable instrument for the systematical documentation and guidance of the development and transformation of an organization [2].

4.1. General procedures of model development

Maturity models share the common property of defining a number of dimensions or process areas at several discrete stages or levels of maturity [9]. Thereby, such a model ideally contains the following components: A number of levels or stages, a denomination for each level, a description or summary of each level, a number of dimensions or process areas as well as specific elements or activities for those, and a description of relevant activities as they might be performed at each maturity level [9]. Proceeding from the assumption, that a maturity model usually contains five levels, staged, continuous and focus area-oriented models can be distinguished [36]. Our model constitutes a continuous approach in which dimensions however are not attributed to a specific level, but vice versa, each dimension passes through the five levels of maturity. Regarding its purpose, a maturity model can aim at “as-is” assessments (descriptive), at indicating on how to identify and reach desirable future levels (prescriptive), or at enabling internal and external benchmarking (comparative), e.g. across industries [6][30]. Our model at this time primarily focuses on a descriptive purpose, but has the potential to address prescriptive and comparative purposes, as well.

With respect to the (structured) development of suitable maturity models, [6]’s framework containing the main phases scope, design, populate, test, deploy and maintain appears to be most suitable for describing the general procedure of model development, not least due to its generic character. In addition, [19] identified a largely comparable approach and both procedures do moreover aim at accompanying the models entire lifecycle. This paper puts special emphasis on the early phases of the framework (scope, design, populate) but will furthermore discuss the testing- and deploying-aspect of our maturity model, as the pursued grounded theory approach virtually synthesizes the design, scope and test phase up to a certain extent. Finally, the deploy phase has already been launched through the publication of results at hand, which makes the results available for early and elementary use.

4.2. Introduction of the maturity model

During the course of investigation, we were able to draw a highly detailed view of the hypothetical and – as far as already prevalent – factual process of digital transformation within companies from the German manufacturing industry. In contrast to already existing maturity models, usually focusing on one model “layer”, we concluded that such a perspective would not serve the purpose of providing a satisfactory detailed view on the object under consideration. This led to the emergence of a multidimensional view on digitalization. It therefore became necessary to create three layers in the sense of abstraction levels.

With respect to the fundamental importance of CPS or smart products within production processes and the supply chain of the future, developments in this regard might be two-folded. On the one hand, a company can focus towards providing additional value through the offering of smart products to its customers. Taking such a path will lead to a shift from product- to service-orientation and to offering value added services based on smart products [27]. On the other hand, the realization of smart products does only constitute one side of the coin. A company can furthermore shift its activities towards the usage of smart products – in this context in most cases understood as CPS or CPPS – and thereby focus on the overcoming of conventional production through the application of such systems itself [38][39]. While it is possible to pursue both objectives at the same time aiming at converting into a (fully) digitalized enterprise, the majority of companies in the short run confines themselves to one of both “paths”, as they are displayed within Figure 1.

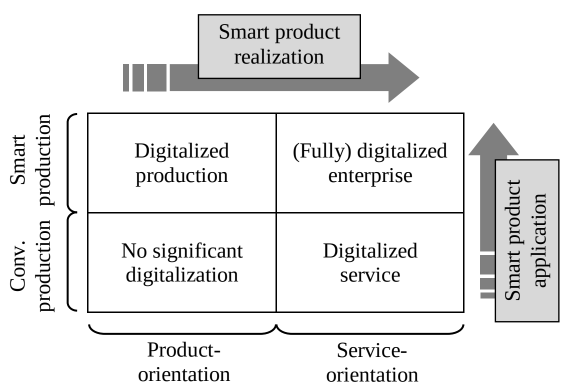

Figure 1. Different perspectives on smart products

The splitting of the process of digital transformation into two different perspectives leads to the instance, that it is possible to speak of two individual maturity models, depicting “smart product realization” and “smart product application”, as shown within Table 2. Both perspectives display certain similarities, as activities on the respective paths may go hand-in-hand or simply do not diverge from another. Nevertheless, an isolated consultation of the single perspectives is likewise applicable as a combined one. Both perspectives do in any case share the same nine dimensions regarding digitalization as well as the five levels passed through towards maturity.

“Digitalization awareness” constitutes a “typical” first level of maturity, as no significant developments took place at this juncture. The respective company nevertheless realizes imminent disruptive changes and corresponding challenges triggered by digitalization and takes appropriate preliminary measures. On a second level (“smart networked products”), the embedding of microelectronics into physical objects following the premises of CPS becomes implemented. Within a “service oriented enterprise”, those objects then provide the basis for “smart” services, whereby the actual ICT-component within such product-service combinations evolves into a rather enabling role. When furthermore “thinking in service systems”, services become aggregated or interconnected to demand-actuated, solution-oriented service systems [3]. This development certainly does not only take place internally, but also – in the sense of a digital enterprise – alongside the whole supply chain. Effectively, the target-condition of digital transformation can already be considered as reached during the fourth maturity level. The “data-driven enterprise” anyhow constitutes a paradigmatic “mindset-change”, in which data and information created by the preceding developments receive particular interest: CPS, with respect to both smart product application and realization, generate data building the foundation for smart services which in turn are aggregated into service systems. They thereby enable the pursuit of new, data-driven business models on which such an enterprise ultimately is based on.

The advancement alongside these five levels of maturity can be depicted and prospectively be measured by nine dimensions resulting in a total of 90 process areas. “Strategy development” in this context refers to the essential adjustments (with increasing maturity) of a company’s strategic orientation. “Offering to the customer” describes the (additional) customer value resulting from the respective level of maturity, whereby a customer can be of both internal and external nature. “Smart product” or “smart factory” identifies the technological adaptions in the sense of a CPS, either with regard to actual products or to CPPS being utilized within production processes. “Complementary IT system” is strongly related to the preceding dimension and describes the associated technological framework, with regard to a new meta-context of digitalization [17]. The necessary measures

Table 2. Digital transformation with respect to smart product realization and smart product application

Smart product realization	Level of maturity				
	Digitalization awareness	**Smart networked products**	**The service-oriented enterprise**	**Thinking in service systems**	**The data-driven enterprise**
Strategy Development	Product roadmap defined and realized	Roadmap for smart products defined and realized	Roadmap for smart services defined and realized	Integrated roadmap for (smart) service systems defined and realized	Roadmap for a data-driven enterprise defined and realized
Offering to the customer	Portfolio of physical products	Smart products with data processing capabilities	(smart) product-service combinations	"Product as a Service" approach established	Services based on (B)DA ("data as a service")
"Smart" product	Conceptual framework for smart products defined	Product with embedded microelectronics	Product with embedded software services	Product with ES and open interfaces	Smart product embedded in a (B)DA infrastructure
Complementary IT system	Reference model for a digitalized enterprise defined	Standardized interfaces for smart products implemented	Complementary innovations implemented	Reference model fully implemented across companies	(B)DA implemented as key innovation
Cooperation	Exchange and transfer of knowledge through innovation networks	Cooperation with technology partners	Cooperation with service providers	Strategic service network (ecosystem) established	(B)DA provider integrated (into the ecosystem)
Structural organization	Promoter on board level	Internal R&D organization adapted	Internal (smart) service organization installed	Service ecosystem unit installed	(B)DA unit installed
Process organization	Defined business processes	PLM process adapted for smart products	CRM process adapted for smart products	SSM process defined and established	DLM process defined and established
Competencies	Competencies for TIM accessible	Competencies in ES accessible	Competencies in Service Engineering and Design accessible	Competencies in SSE accessible	Competencies in (B)DA accessible
Innovation culture	Openness for digital technologies	Focus on (smart) product-service combinations	Service innovation thinking established	Digital enterprise thinking established	Understanding of data as an important value carrier

Smart product application	Level of maturity				
	Digitalization awareness	**Smart networked products**	**The service-oriented enterprise**	**Thinking in service systems**	**The data-driven enterprise**
Strategy Development	Lean production implemented	Use case roadmap for smart production defined and realized	Sourcing strategy for service providers defined	Strategy for ecosystem development defined	Roadmap for a data-driven enterprise defined and realized
Offering to the customer	Portfolio of physical products	Intended value added for customers defined	Value added services implemented	Production transparency and visibility established	Services based on (B)DA ("data as a service")
"Smart" factory	Conceptual framework for a smart factory defined	Relevant CPPS defined and specified	CPPS implemented and running	CPPS embedded into a (smart) service system	CPPS embedded into a (B)DA infrastructure
Complementary IT system	Reference model for a digitalized enterprise defined	Data integration platform implemented	Complementary innovations implemented	Reference model fully implemented across companies	(B)DA implemented as key innovation
Cooperation	Exchange and transfer of knowledge through innovation networks	Cooperation with solution providers	Cooperation with service providers	Strategic service network (ecosystem) established	(B)DA provider integrated (into the ecosystem)
Structural organization	Promoter on board level	Internal IT organization adapted	Internal (smart) service organization installed	Service ecosystem unit installed	(B)DA unit installed
Process organization	Defined business processes	Concept for fully digitalized business processes defined	Fully digitalized business processes established	SSM process defined and established	DLM process defined and established
Competencies	Competencies for TIM accessible	Competencies in CPPS accessible	Competencies in Service Engineering and Design accessible	Competencies in SSE accessible	Competencies in (B)DA accessible
Innovation culture	Openness for digital technologies	Openness for service thinking	Service innovation thinking established	Digital enterprise thinking established	Understanding of data as an important value carrier

(B)DA: (Big) Data Analytics; ES: Embedded Systems; R&D: Research and Development; PLM: Product Lifecycle Management; CRM: Customer Relationship Management; SSM: Service Systems Management; DLM: Data Lifecycle Management; TIM: Technology and Innovation Management; SSE: Service Systems Engineering; CPPS: Cyber Physical Production Systems; IT: Information Technology of “cooperation” with supply chain partners are depicted as well as they have to be intensified with respective maturity progress. “Structural Organization” identifies essential adaptions concerning the organizational anchoring of digitalization inside a company, while “process organization” refers to adaptions necessary with respect to the company’s core business processes. “Competencies” identifies relevant knowledge and skills, on which a company must assure direct access in order to realize digital transformation. Finally, digitalization also requires a change within the “innovation culture”, which is underpinned by a quote attributed to management-pioneer Peter Drucker, stating that “culture eats strategy for breakfast”.

With respect to the “broad” field of observation, systematic coding, more precisely the generation of categories from the vast amount of open codes identified from studying the interview-transcripts in the sense of axial and selective coding, constituted certain challenges. With respect to that instance and the at first sight fuzzy-seeming processes of grounded theory research, certain controversies might arise when openly discussing the particular dimensions and maturity levels. However, the dimensions and maturity levels displayed within Table 2 do contain the greatest possible extent of contextual selectivity and do thereby enable the depiction of a digital transformation process in a highest possible granularity.

Another controversial discussion might arise from whether the third component of our maturity model actually constitutes a layer on its own. However, after splitting the process of digital transformation into two separate perspectives, this part puts both of them back together, enabling a summarizing graphical overview. This is achieved through transferring the progress of the certain dimensions alongside the five levels of maturity into a radar chart, as shown in Figure 2.

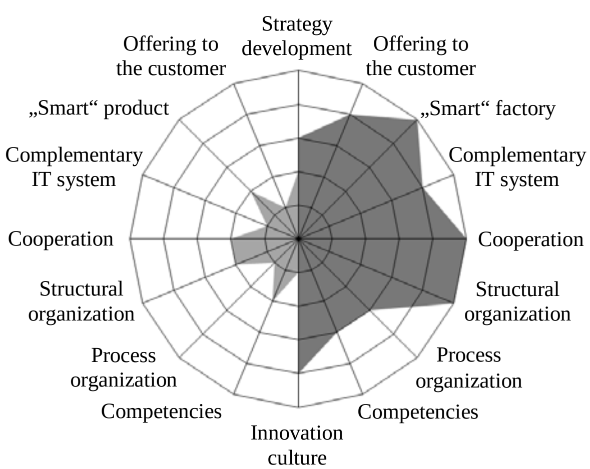

Figure 2. Radar chart for maturity visualization on the example of Company A

Within this visualization, the perspectives of smart product realization (left) and smart product application (right) are lined up against each other, so that decision makers do gain the possibility of rapidly identifying the focus of their own company’s digitalization activities. In addition, this format also comprises potentials for internal and external benchmarking. With respect to a better understanding, Figure 2 depicts the state of maturity on the example of a guided self-assessment of Company A from our interview sample.

5. Conclusion and future work

The objective of this paper was not only the development of a suitable, to a furthest possible extent generic, and comprehensive maturity model addressing digitalization within the manufacturing industry, but also the thorough, transparent, and accountable documentation of the process behind it. In order to reach this objective, the well-established scientific procedures of grounded theory became subject to examination, both with respect to general methodological aspects and to the specific context. Furthermore, the introduction of the actual maturity model was accompanied by a general examination of relevant aspects concerning the development and construction of maturity models.

The value added by our maturity model resides in the combination of scientific rigor, practical relevance and its certain degree of general applicability. The fulfillment of these quality criteria can among others be evidenced through the sufficient addressment of relevant design-requirements within our research project [2]. The models unique structure and multi-dimensional perspective further enhances the potential contribution to the scientific community and its validity for economic practice. Limitations on the other hand might reside within the restriction of the evaluation process on informants from German industrial companies. While such a convenience sample is common in many cases, a certain regional focus cannot be neglected and further research might need to be expanded by an international perspective. Nevertheless, conclusions drawn from the observation of one of the largest economies in the world with a variety of global market leaders in almost every industry-sector should provide at least a certain amount of international and cross-industrial applicability. Another potential limitation has to be mentioned with respect to the persistently changing object under observation and the resulting dynamics of the target system. This instance accompanied the whole research process increasing the difficulty of identifying a hypothetical optimum, usually required within maturity model development. With further emergence of the various aspects of digitalization, the research results might have to be reviewed and revised. This aspect almost directly leads to the discussion emerging from our interviews, to what extent "perfect" maturity is required. Not every company might have to undergo the entire process of digital transformation, but instead identify its individual optimum somewhere "on the way". We are nevertheless confident, that our maturity model already addresses this aspect sufficiently. A last limitation constitutes the lack of "theorization", usually walking along with publications of this kind. This becomes particularly clear when reviewing the numerous (90) single process areas of the second model layer. A depiction with this level of detail would easily go beyond the scope of this paper. This is why we tried to make the visualizations of our model self-explanatory to the furthest possible extent. Nevertheless, the further specification of each dimensional attribute is a necessity for the future in order to provide a highly detailed description of the several levels, dimensions, process areas, and activities [15]. At this point, it might also be of value to leave the interview data behind and turn towards already existing scientific and practical literature, addressing one or more isolated aspects of the model.

The central content-oriented objective of this paper was the reduction of complexity regarding digital transformation by depicting this process in a clear and generic manner, as usual in case of an descriptive maturity model. It would in a next step be of interest to further particularize the dimensions, maturity levels, and process areas, although the perceptions from the previous chapter do mostly speak for themselves. By detailing these aspects, it should furthermore be possible to derive recommendations for actions leading to a more prescriptive maturity model and to enabling a quantifiable determination of position and progress within the model. In addition, the third layer depicted in Figure 3 shows additional potential for internal and external benchmarking, possibly also with regard to specific typologies of companies undergoing digital transformation. Thereby, our model would serve all three typical purposes for the creation and use of maturity models, as illustrated by [6]. It would be of particular interest at this point, not only to display maturity, but also to moreover operationalize and quantify it, for instance through the use of assessment questions [37]. Admittedly, our rather descriptive model has for now some remaining deficits regarding the impartial measurement of the current maturity level of a particular company. This research gap is intended to be closed in a timely manner, among others by additional elaborations concerning the second and third model layer. The central motivation behind this approach is the development of an "audit tool" [9], enabling the quantified measurement of maturity either by an external auditor, by self-assessment, or by a certified practitioner [6]. For future research, even the evolution of the model towards a partially or even completely automated tool might reach the realms of possibility. To that respect, especially additional operationalization aspects [15], such as the potential support of weighting capabilities, come to the fore. The realization of the aforementioned aspects should make it possible to not solely focus on single companies, but to furthermore turn towards cross-sectional and longitudinal elevations, e.g. in case of particular countries, regions or specific industrial sectors. Certainly, additional measures of evaluation in the sense of (field) testing appear to be necessary, before the maturity model lifecycle can be proceeded in the sense of a broad practical and empirical application, which will then also answer the question of the model's generalizability [6].

As a concluding remark, it can be stated that a near-time transfer of our maturity model into economic practice appears to be a logical target for future activities. We are thus confident that our contribution is not only suitable for providing structured insights into the scientific field of digitalization, but also for supporting the transformation of today's companies and supply chains into their digitalized counterparts.

6. References

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