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Development of an Organizational Maturity Model in Terms of Mass Customization

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8.1 Introduction

Production technologies are, these days, mostly affected by dynamic development of information technology and automatic identification technologies. Obviously, technological changes are driven by many factors such as increasing requirements of individual customers, safety and environmental standards, social demands, the diffusion of disruptive innovations, and so on. In general, technology is changing very rapidly and the newest technological developments are reshaping the manufacturing sector in its original form. For example, additive manufacturing, cloud computing, radio frequency identification, fifth-generation wireless systems, and the Internet of Things (IoT) are only a few of the

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new technologies that are driving a paradigm shift in manufacturing. The umbrella term for this new wave of so-called smart manufacturing is Industry 4.0 (Kagermann et al. 2013). The main objectives of Industry 4.0 can be characterized, in a simple way, as the introduction of intelligent applications and smart sensor device in production, logistics and business models. Moreover, new information and communication technology (ICT) and web technologies act as enablers of smart, autonomous, and self-learning factories. According to some authors as Sommer (2015), Rauch et al. (2018), successful implementation of Industry 4.0 has to take place not only in large enterprises but in small- and medium-sized enterprises (SMEs) as well. Therefore, a great challenge for the future lies in the transfer of Industry 4.0 expertise and technologies to this size of manufacturing firms that represent the backbone of regional economies. Although there is high potential from Industry 4.0 in SMEs, the main limit lies in a lack of methodological frameworks for its introduction and wide implementation. In addition, a growing number of factories are facing the challenges of even more individualized and customized products (Modrak 2017). This is also the case among SMEs, which are involved in global business and facing a demand for increased product variety (Brunoe and Nielsen 2016). In this context, this chapter aims to help overcome this gap through proposed approaches and solutions.

The chapter is divided into several sections. After this section, the existing approaches to maturity models for the application of Industry 4.0 (I4.0) concept are presented and analyzed. Next, the problem description gives a short explanation of why managerial and organizational concepts, supporting models, and quantitative indicators can be helpful in the introduction of I4.0 in manufacturing companies. The methodological steps of the presented research are graphically depicted in Sect. 8.4. The development steps of the proposed maturity model (MM) are described in detail in the subsequent Sects. 8.5 and 8.6. This part of the chapter presents its main contribution to the managerial and organizational models for the introduction and implementation of I4.0 in terms of mass customization (MC). The final section offers future directions and summarizes the major results of this chapter.

8.2 Literature Review

In general, advanced technologies, including those related to I4.0, infiltrate permanently into all spheres of human life in developed countries. On the other hand, Cotteleer and Sniderman (2017) argue that "there is little doubt that penetration of Industry 4.0 concept in companies' processes and operations will grow." Moreover, some authors (e.g., Hofmann and Rüsch 2017) were skeptical about companies' efforts in this area since according to them the "concept of Industry 4.0 still lacks a clear understanding." This corresponds with a limited occurrence of literature that deals with the concept of Industry 4.0 or smart manufacturing from methodological viewpoints and clarifies how to successfully implement the main components of I4.0 into manufacturing practice. Smart factories can be characterized by distinctive features that reflect different aspects of the domain of interest. According to Pessl et al. (2017) smart factories represents the connection between digital and physical production networks known also as cyber-physical systems. In particular, the integration of computing, wireless, and Internet technologies makes this connection possible. IoT is the most critical component for connecting devices without wired connection (Avram et al. 2017; Belforte and Eula 2012; Ahuett-Garza and Kurfess 2018). For this reason, some of the biggest challenges for manufacturing companies is to increase the level of digitization, to adapt production lines to new technologies or to define the role of humans within new processes (Fang et al. 2016). Toward these outcomes, different MMs can help to identify where the company currently operates and what needs to change. Moreover, maturity models offer comprehensive guidance and introduce and create a basis for evaluating the progress in the maturity of process or a technology. Most maturity models are dedicated to assessing people, culture, processes, structures, and objects or technology, respectively (Mettler 2011). Tavana (2012) pointed out that "the most important point of critique is the poor theoretical basis of maturity models." Becker et al. (2009) proposed evaluation criteria and a generic methodology for the development of maturity models and applied them to the maturity model for IT management. Several authors adopted their recommended steps for developing maturity models related to I4.0. For instance, Leyh et al. (2017) offered an MM for classifying the enterprise-wide IT and software Landscape from the I4.0 perspective, and recommended activities, which can enable a company to reach individual maturity stages. Similarly, Schumacher et al. (2016), and Sternad et al. (2018) have been inspired by their methodology and applied their recommendations to the development of Industry 4.0 related readiness and maturity models. Kese and Terstegen (2017) categorize four types of MM in terms of I4.0. Another classification concept was proposed by Barata and da Cunha (2017), who recommend classifying MM into two groups, i.e., practical models for specific applications or generic MM for I4.0 and its sub-domains. According to Fraser et al. (2002), it is also useful to distinguish between so-called maturity grids, capability MM models or Likert-like questionnaires MM.

In order to compare and analyze existing readiness maturity models, roadmaps, and conceptual frameworks related to Industry 4.0, it is useful to present them in a structural form by pointing out their relevant attributes. Related works with their characteristics are presented in Table 8.1.

Based on this review, the 20 identified and investigated literature sources were dedicated to one or more of three types of methods namely, I4.0 readiness MMs, roadmaps, and conceptual frameworks. It is necessary to note that specific capability maturity models can also be understood as evolutionary roadmaps for implementing the best practices or methodologies into company processes (Curtis et al. 2001). Here identified systematic roadmaps are presented in explicit form, and they might enable companies to answer questions about what technologies to develop when and how. The quantitative occurrence of each type of method was as follows: I4.0 MMs—17 literature sources, the roadmaps—5 literature sources, and the conceptual frameworks—5 papers.

The literature sources used in Table 8.1 can be classified into two basic categories: academic literature, and nonacademic literature. In general, journal papers and conference proceedings represent scientific research, and the latest developments in a specialized field (Wong and Monaco 1995). Rigorous academic books can be included in the first category, too. Then, the academic literature used in our review consists

Table 8.1 Comparison of literature sources dedicated to MMs, roadmaps, and conceptual frameworks

Author(s) and year of publication	Type of the publication	Nature of the method used	The method description and levels of MMs	Subject(s) of interest
Katsma et al. (2011)	CP	I4.0 readiness MM and architectural framework	It contains four stages that describe the development from ERP to the IoT. The stages are applied to four different dimensions	SCM, In-house logistics
Rockwell Automation (2014)	FP	Roadmap and IT readiness MM	Connection of y to IT. Maturity Model divided into 5 stages	Operation technology, IT, SCM, employees
Lichtblau et al. (2015)	FP	I4.0 readiness MM	MM proposes 6 maturity levels that measure the Industry 4.0 readiness. It contains an action plan to boost the readiness in the context of technology, environment, and organization	Organizational aspects, products, operation technology, employees, data management
Bitkom et al. (2016)	FP	Reference Architecture Model for I4.0	A 3D model reflects smart grid architecture model, which was defined by the European Smart Grid Coordination Group	Business layer, functional layer, information layer, communication layer, integration layer, asset layer

(continued)

Table 8.1 (continued)

Author(s) and year of publication	Type of the publication	Nature of the method used	The method description and levels of MMs	Subject(s) of interest
Geissbauer et al. (2016)	FP	Roadmap and I4.0 readiness MM	Definition of six practical steps that a company needs to take to lead tomorrow's competitive digital landscape. MM divided into 4 levels	Employees, company culture
Ganzarain and Errasti (2016)	JP	Business model framework, Roadmap, and I4.0 readiness MM	Three stage maturity model in SME's toward Industry 4.0	Product, organizational aspects
Chromjakova (2016)	JP	I4.0 readiness MM	Performance management system for Industry 4.0. Three-stage MM	Process, product employees
Leyh et al. (2016)	CP	I4.0 readiness MM	MM enables organizations to evaluate IT capabilities for I4.0. It consists of five levels with four dimensions	IT, software, technological aspects
Schumacher et al. (2016)	CP	I4.0 readiness MM	The model is dedicated to manufacturing companies. It consists of five maturity stages, which are applied to nine dimensions	Products, customers, operation technology, strategy, leadership, data management, culture, employees

(continued)

Table 8.1 (continued)

Author(s) and year of publication	Type of the publication	Nature of the method used	The method description and levels of MMs	Subject(s) of interest
Singh et al. (2017)	CP	Generic enterprise architecture	It describes enterprise architecture for a smart logistics of business processes	Logistics of business processes, big data, production planning
Kumar and Namapuraja (2018)	FP	I4.0 readiness MM	A methodology is based on holistic and multidimensional approach to assess current readiness for Industry 4.0 journey using 6 levels	Organizational aspects, company culture, IS
Hofmann and Rüsch (2017)	JP	I4.0 application model	Focused on logistics management. Divided into two dimensions	SCM, data management
Gökalp et al. (2017)	B	Roadmap and I4.0 readiness MM	Industry 4.0-Maturity Model for manufacturing processes is divided into six levels and five dimensions	Asset management, data management, enterprise management, process transformation, organizational aspects
Jæger and Halse (2017)	B	I4.0 readiness MM	The IoT technological maturity model determines the current IoT implementation level for manufacturing enterprises. It introduces eight maturity stages	IoT-technologies, manufacturing technologies

(continued)

Table 8.1 (continued)

Author(s) and year of publication	Type of the publication	Nature of the method used	The method description and levels of MMs	Subject(s) of interest
De Carolis et al. (2017)	B	Roadmap and I4.0 readiness MM	The digital readiness assessment maturity model (DREAMY) guides manufacturing companies toward digitalization. MM consists of five maturity levels and four dimensions	Processes, monitoring and controlling, manufacturing technology, organizational aspects
Li et al. (2017)	CP	I4.0 readiness MM	Proposed Capability Maturity Model aims to evaluate the maturity and readiness of manufacturing enterprises from the factory operations perspective using 5 levels	Operation technology
Klötzer and Pfaum (2017)	CP	I4.0 readiness MM	Maturity model is dedicated to digital transformation of manufacturing enterprises. MM is divided into 5 levels	Products, IT, organizational aspects, processes, company culture

(continued)

Table 8.1 (continued)

Author(s) and year of publication	Type of the publication	Nature of the method used	The method description and levels of MMs	Subject(s) of interest
Weber et al. (2017)	CP	I4.0 readiness MM	MM analyzes the IT architecture of manufacturing companies to provide a development path toward servitization. MM is divided into 6 levels	IT, IS, data management
Werner-Lewandowska and Kosacka-Olejnik (2018)	CP	I4.0 readiness MM	Maturity model is focused on logistics operations in service companies. MM is divided into 6 levels	Logistics
Sternad et al. (2018)	JP	I4.0 readiness MM	MM enables self-evaluation of the company and covers the development areas. MM is divided into 5 levels for logistics 4.0	Logistics, business models, IT, IS, processes, enterprise management, production planning, production control, human-machine communication
Legend:		*Abbreviations*:		
Firms' publication (FB) Conference paper (CP) Journal paper (JP) Book or Book chapters (B)		ERP—Enterprise resource planning SCM—Supply chain management IT—Information technology IS—Information system		

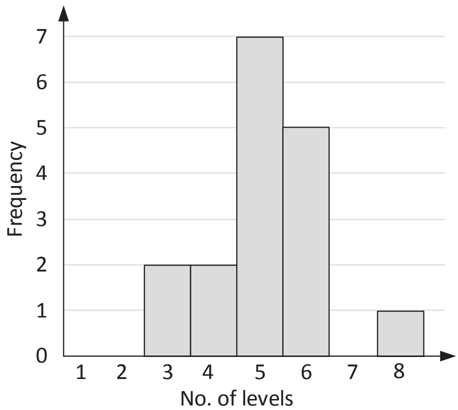

Fig. 8.1 Frequency distribution of the progress levels used in the reviewed MMs

of 15 references, and the nonacademic literature is represented by 5 literature sources.

When analyzing levels of the examined I4.0 MMs, they vary from 3 to 8 stages. Frequency distribution of the levels used in the reviewed MMs is depicted in Fig. 8.1. As can be seen, the most commonly occurring number of levels in the MMs is 5. This is in line, e.g., with the representative generic capability MM for software process program which also uses 5 stages of maturity progress (Paulk et al. 1993).

Our next interest was to learn which domains of MMs dominated in the investigated literature. For this purpose, the following diagram in Fig. 8.2 is provided.

As shown in Fig. 8.2, the domains of interest can be divided into two categories classified as "essential domains" and "recommended domains." Then, the domains with a frequency of 4–6 fall into the first category, and the rest of the subjects of interest belong to the second category.

8.3 Problem Description

As mentioned above, a great challenge for SMEs lies in the transfer of I4.0 expertise and technologies to their environment. Moreover, this challenge also includes transfer toward mass customization. Comparing

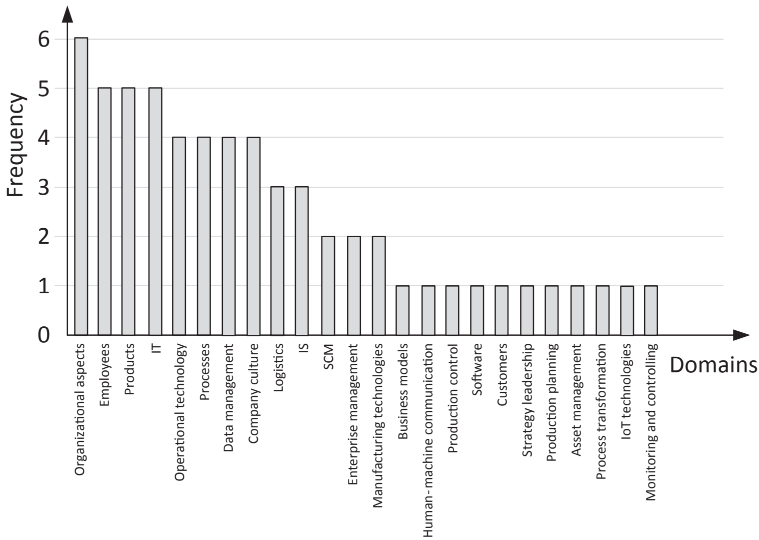

Fig. 8.2 Categorization of subjects of interest based on their appearance in the I4.0 MMs

starting conditions for introduction of the I4.0 concept between large companies and SMEs, it can be stated that larger companies can follow the higher maturity levels in the technological domain for this concept more quickly than SMEs. This is because they can invest more money, time, and expertise into this transfer. On the other hand, an advantage of SMEs against large companies is lower complexity of their business and manufacturing processes. And thus, organizational and cultural changes can be implemented into the whole enterprise much more easily.

Even though several I4.0 MMs which focused on organizational facets were identified in the aforementioned section, none of them can be considered as standardized or universal. Moreover, the described approaches in Table 8.1 were mostly based on self-assessment by using questionnaires which offered answers yes or no, and were oriented toward the identification of a company's current state related to the maturity requirements. Reflecting on the findings of the review from Sect. 8.2, the ambition of our research is to develop a comprehensive I4.0 MM focused on organizational and managerial aspects in terms of mass customization. The proposed I4.0 MM is based on a collaborative approach using a questionnaire method for self-assessment described further in Sects. 8.5.1 and 8.5.2. The outputs of this questionnaire maturity model (QMM) are dedicated to identifying status quo and mapping gaps which need to be filled in order to reach the planned state and are further used as inputs for the creation of the I4.0 readiness MM. Moreover, our approach includes the methodological recommendations in form, e.g., how to measure progress in product modularity and process modularity using quantitative indicators. In addition, we propose a generic organizational model of mass customized manufacturing as a condition for reaching an advanced stage (Level 4) of the proposed MM.

8.4 Methodology

The aim of this section is to guide you through the process of developing the managerial and organizational maturity models. This process starts with a structural analysis of the existing literature related to I4.0 MMs (Sect. 8.2). It helped us to identify what methods already exist, to understand the relationships between them, to find out which domains are essential for I4.0 introduction, and so on. Based on the obtained findings, it was easier to specify categories and levels of QMM for mapping of requirements of SMEs to meet higher maturity levels in the context of the strategy for Industry 4.0. The method used for this purpose is described in detail in Sect. 8.5.1. Subsequently, application of the QMM is presented in Sect. 8.5.2. Respondents were represented by 10 selected SMEs. The next step in our approach was aimed at specifying differences between current states and required states and identifying the key requirements of SMEs on the bases of the obtained results from the questionnaire. In order to validate the obtained results, the overall internal consistency of the questionnaire was measured by Cronbach's alpha coefficient (see Sect. 8.5.3). Development of the I4.0 readiness MM (I4.0 RMM) that is shown in Sect. 8.6, followed methodological recommendations from the relevant scientific publications dealt with in Sect. 8.2. Finally, based on empirical experiences, the generic organizational model of mass customized manufacturing was proposed (see Sect. 8.6.1). The whole methodological framework in the form of a step-by-step guide is available in Fig. 8.3.

8.5 Proposed Approaches and Solutions

This section will provide readers with substantial research outputs that are outlined in Fig. 8.3.

8.5.1 Development of QMM

The QMM method was selected with the aim of applying the collaborative approach by involvement of selected SMEs in order to identify their current status and define future targets in the context of I4.0 challenges. In order to map the requirements of SMEs to meet planned maturity levels in the context of the strategy I4.0, the categories of the QMM for investigation of the managerial and organizational model, were firstly defined. For this purpose, five categories were empirically selected in our previous work, which are business strategy, business models related to product, innovation culture, organizational production model, and knowledge management (Modrak et al. 2019). For each of the categories, five maturity levels were specified in descriptive form as shown in Appendix 8.1.

After the SMEs' self-assessment, obtained questionnaire outputs resulted in specification of their key requirement. The questionnaire form contained options scaled from the lowest level (L1) to the highest level (L5) as shown in Appendix 8.4.

The obtained results from the fulfilled questionnaire forms are presented in the next section and considered further in Sect. 8.5.3.

8.5.2 Application of the QMM

Results from the mapping of requirements using the QMM method to identify the current situation and future targets of the 10 companies are graphically depicted in Fig. 8.4.

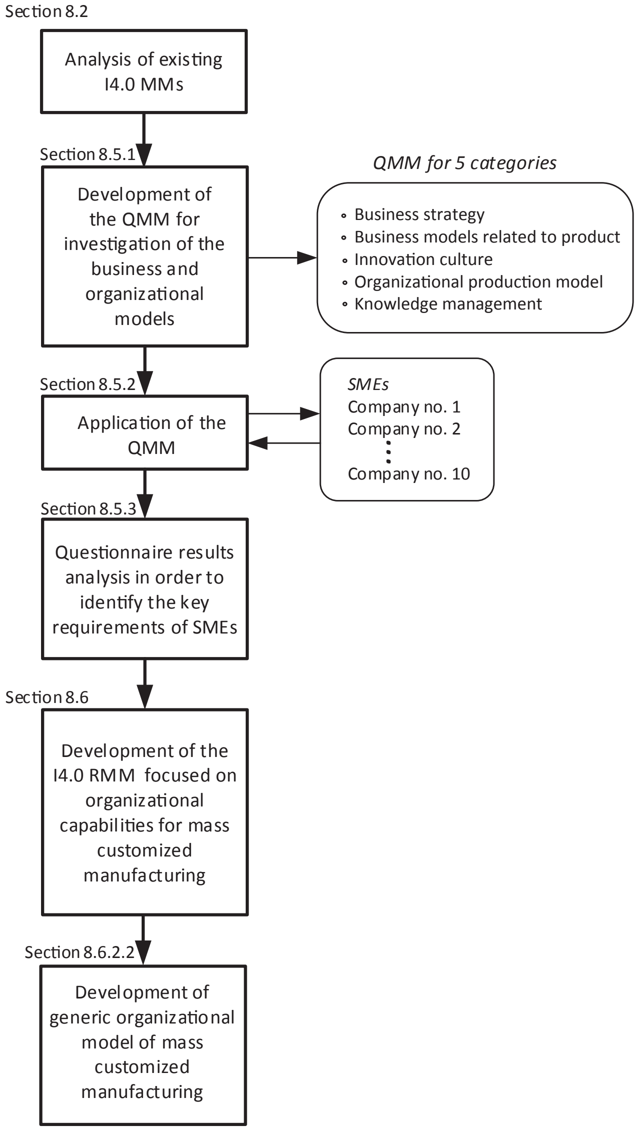

Fig. 8.3 Research methodological framework

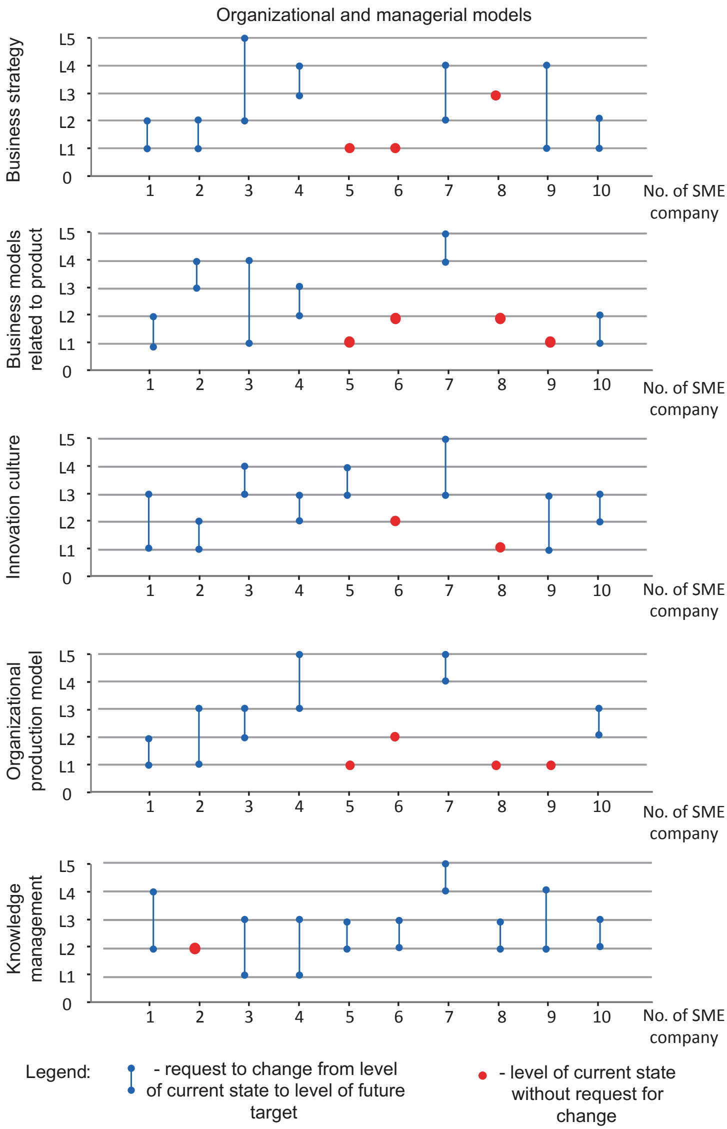

Fig. 8.4 Results from mapping of individual requirements

According to the obtained results shown in Fig. 8.4, it is possible to start with their processing in order to identify the key requirement(s) of SMEs in line with given research objectives.

8.5.3 Identification of the Key Requirement of SMEs

In this step, questionnaire results were processed in the following way.

For determination of the order of significance of assessed categories, the weight coefficient (*V*) was used:

$$V = \sum_{i=1}^{10} R_i \cdot W_i \tag{8.1}$$

where,

R_i—the Rate of the change of *i*-th SME, while if the current state is the same as future target then R_i equals 0, and vice versa, R_i equals 1.

When $R_i = 1$, then for each gap between current state and future target a Weighting value (*W*) is assigned. The weighting value depends on the level of change.

When the extent of the gap equals: 1, then $W_i = 1.2$

2, then $W_i = 1.4$
3, then $W_i = 1.6$
4, then $W_i = 1.8$
5, then $W_i = 2$.

The order of categories of significance based on the result values of the coefficient *V* calculated using Eq. (8.1) are as follows: Category No. 5 ($V = 11.6$); Category No. 3 ($V = 10.2$); Category No. 1 ($V = 9.4$); Category No. 2 ($V = 7.6$) and Category No. 4 ($V = 7.6$).

Then, identification of the key requirement(s) will be determined as follows:

Firstly, the Average level of the current state levels (CL_A) for each category is enumerated using the arithmetical mean from 10 values of the level numbers:

$$CL_A = \frac{\sum_{i=1}^{10} L_i}{10}. \tag{8.2}$$

Secondly, the Average level of the future target levels (RL_A) for each category is determined analogically:

$$RL_A = \frac{\sum_{i=1}^{10} L_i}{10}. \tag{8.3}$$

Finally, the average gap for each category is obtained as the difference between RL_A and CL_A. The obtained average gaps are graphically shown in Fig. 8.5.

However, the overall internal consistency of the questionnaire has to be measured by Cronbach's alpha (Cortina 1993) to validate results from fulfilled questionnaires from the population sample represented by 10 SMEs (S1, S2, …, S10). This chapter contains results from a questionnaire survey in the domain of business and organizational models,

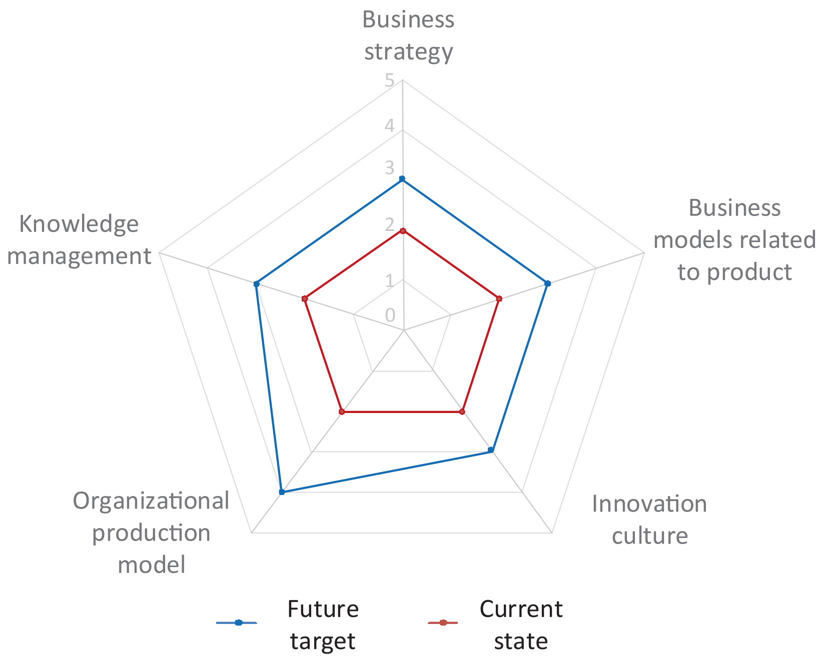

Fig. 8.5 Spider graph of differences between current states and future targets

which was a part of the QMM used for the other two domains, i.e., smart logistics and smart manufacturing with a total number of 15 questions (see Appendices 8.2 and 8.3). Due to this fact, overall internal consistency of the questionnaire used in the QMM will be tested for all three domains. For this purpose, the obtained input data needed to calculate Cronbach's alpha coefficient were arranged into Table 8.2.

Subsequently, Cronbach's alpha coefficients were separately calculated for the current states and the future targets by using the formula (Machin et al. 2007):

$$\alpha = \left(\frac{k}{(k-1)}\right) * \left(1 - \left(\frac{\sum(s_i^2)}{s_t^2}\right)\right), \tag{8.4}$$

where,

k = number of items—questions in questionnaire (Q),
S_i = SD of ith item,
S_t = SD of sum score.

Table 8.2 Input data for calculations of Cronbach's alpha coefficients

	Q1		Q2		Q3		Q4		Q5		Q6		Q7		Q8		Q9		Q10		Q11		Q12		Q13		Q14		Q15	
S1	1	2	2	3	1	1	1	2	2	2	2	4	2	4	1	3	3	5	2	3	1	2	1	2	1	3	1	2	2	4
S2	2	3	2	3	2	2	2	3	2	2	1	2	2	3	1	3	2	4	2	2	1	2	3	4	1	2	1	3	2	2
S3	1	3	2	4	1	2	2	4	1	2	2	3	2	4	2	4	2	4	2	4	2	5	1	4	3	4	2	3	1	3
S4	2	4	3	4	2	3	3	4	2	3	2	4	4	5	2	4	3	5	3	5	3	4	2	3	2	3	3	5	1	3
S5	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	2	2	3	3	1	1	1	1	3	4	1	1	2	3
S6	1	1	2	3	1	1	2	2	1	1	1	2	2	3	2	3	2	2	2	2	1	1	2	2	2	2	2	2	2	3
S7	4	4	3	4	2	2	3	4	2	3	4	5	4	4	3	4	2	5	3	4	2	4	4	5	3	5	4	5	4	5
S8	2	2	2	2	2	2	2	2	2	2	1	2	2	2	1	2	2	3	2	2	3	3	2	2	1	1	1	1	2	3
S9	1	3	2	5	1	5	1	5	1	4	1	5	1	5	1	5	1	5	1	4	1	4	1	1	1	3	1	1	2	4
S10	1	2	2	3	2	3	2	3	2	2	1	2	3	4	3	3	2	3	3	4	1	2	1	2	2	3	2	3	2	3

- Current state (white cells)
- Required state (grey cells)

Then, Cronbach's alpha coefficient for the current states is 0.92 and the future targets equal 0.94. Based on a commonly accepted rule for describing internal consistency using Cronbach's alpha, in both cases, the internal consistencies are excellent.

According to the obtained results, the category titled "organizational production model" was specified by 10 SMEs as the key requirement (see Fig. 8.6) and for this key requirement will be further proposed an I4.0 readiness MM with an orientation toward organization capabilities for mass customized manufacturing.

8.6 Maturity Model of Organizational Capabilities for Mass Customized Manufacturing

In this Section, the I4.0 readiness MM is proposed including a recommended specification for SMEs as preconditions for successful implementation of mass customized manufacturing. Presented I4.0 RMM is divided into 5 stages: conventional, starting, moderate, advanced, and optimized, as depicted in Fig. 8.6. The structure of its characteristics can be divided into two groups.

The first one includes the main features of the stages such as: product standardization, product modularity, process modularity, integration of product configurator into process planning, and optimization of intelligent technologies and products. The main features of the first group can be formally modeled by using the arithmetic recursive formula:

$$a_n = a_{n-1} + d \tag{8.5}$$

where n are integers 1–5,

$a_0 = 0$,

and d is common difference (in our case "one step up").

Then, the 1st step up is represented by product standardization, and the 5th step up relates to optimization of intelligent technologies and products.

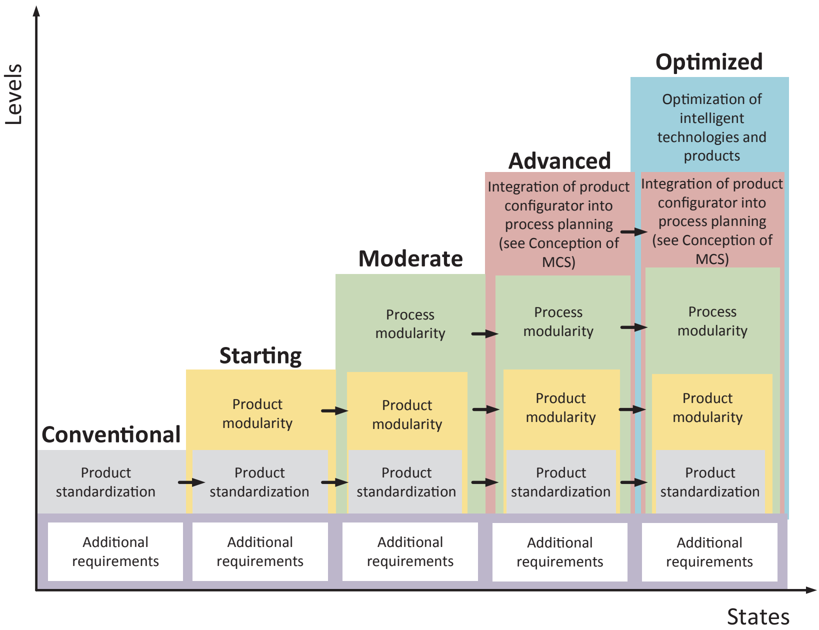

Fig. 8.6 I4.0 RMM of organizational capabilities for mass customized manufacturing

The second group consists of additional requirements that are described in Sect. 8.6.1. The list of additional requirements is only informative, and can be subject to variations.

8.6.1 Additional Requirements of the Maturity Model

The additional requirements of the I4.0 RMM might include at least the following characteristics.

At the Conventional stage:

- Traditional approach based on product standardization of particular products offered for different markets
- Common operational planning methods, communication with suppliers using basic ICT technology, manual processing of orders and logistics, no monitoring of logistics

- Production not connected with ERP system through manufacturing execution systems (MES)
- Physical product without digital functions, sporadic combination of products and digital services.

At the Starting stage:

- Orientation of product modularization
- Assessment of suppliers coordinated with logistics and production, ERP system connected with production through MES
- Internally integrated system-based planning, optimization of logistics operations
- Data analysis for mass customized production needs
- Groups of standardized products are shipped to different markets according to local needs.

At the Moderate stage:

- Orientation on process modularization
- Integrated customer solutions across supply chain boundaries, collaboration with external logistics providers, transfer of product characteristics to the ERP system for marketing purposes
- Individualized customer approach and interaction with supply chain partners by using specific ICT technology
- IT integration with suppliers through ERP system
- Partial focus on the development of intelligent technologies and products.

At the Advanced stage:

- Using product configurators to enhance communication with clients who are ordering customized products
- Adaptation of organizational model of production for mass customized production
- Transition to one-piece flow production in order to increase effectiveness of manufacturing processes

- Application of modern ICT and automatic identification technologies for monitoring and tracking of parts, components, modules, and final products in manufacturing plant and supply chains.

At the Optimized stage:

- Optimization of the organizational model of production for mass customized products
- Optimization of product modularity and process modularity by using quantitative metrics
- Communication with suppliers is completely digitalized, intensive optimization of warehouses, real-time transparency of supply chain
- Application of tools for digital marketing and sales
- Optimization of intelligent technologies and products.

8.6.2 Description of the Main Features of the Maturity Model

The first important features of preconditions of organizational capabilities for mass customized manufacturing that are indicated in our I4.0 readiness MM, are product standardization, product modularity, and process modularity. As is well-known, standardization of the internal components simplifies their assembly into many different products according to a customer's needs (George 2003). It can also be stated that modularity-based approaches in manufacturing practice such as product modularity and process modularity can improve mass customization capability and are strong enablers of this marketing and manufacturing strategy (Kotha 1995; Gilmore 1997). Accepting these statements is one thing, but when companies want to follow the steps shown in our I4.0 readiness MM, they need to manage improvements of these features. However, we also have to accept a common rule: if you can't measure it, you can't manage it. Therefore, it is recommended that effective quantitative measurement for this purpose is applied; this is described below.

8.6.2.1 Product Modularity and Process Modularity

There are several approaches to measure product modularity, which are available in the literature. A comprehensive overview of them has been offered by Ulrich (1994). Hölttä-Otto and De Weck (2007) proposed a product modularity metric called the Singular Value Modularity Index (SMI) to quantify the degree of modularity of a product on its internal structure. SMI is theoretically bounded between 0 and 1, while SMI closer to 1 indicates a higher degree of modularity and vice versa. For its calculation, the following expression is used:

$$\mathrm{SMI} = 1 - \frac{1}{N \cdot \sigma_1} \sum_{i=1}^{N-1} \sigma_i(\sigma_i - \sigma_{i+1}), \qquad (8.6)$$

where:

N—is the number of components of the system

σ_i—represents singular values, $i = 1, 2, \ldots, N$ ordered in decreasing magnitude.

The authors of this measurement approach provide in the above mention literature sources useful examples of how the SMI measure can be applied.

According to Calcagno (2002), not only is a product modularity measurement important, but it is also necessary to measure a degree of modularity of manufacturing systems. On the other hand, there is a dearth of process modularity measures, which could be simply applied for managerial purposes. For this reason, we proposed to adopt the SMI to measure the degree of modularity of manufacturing processes (Modrak and Soltysova 2018a).

Process modularity issues are important, particularly in the context of optional components entering into an assembly station with a human presence. As a consequence, such a station might be divided into two or more substations to minimize complexity of the operation in order to eliminate the tendency to make mistakes. The important precondition to applying SMI for process modularity is transformation of real process operations into models using graph theory. A methodological procedure of how to apply SMI to measure process modularity can be found in the mentioned literature.

8.6.2.2 Integration of Product Configurator into Process Planning

The proposed generic model of how to organize manufacturing and marketing activities in terms of mass customization is depicted in Fig. 8.7. The model can be divided into four systems, namely the product configuration system, product arrangement and process planning system, manufacturing system, and final product assembly system. The product life cycle in this segment starts in the configuration system, where the product is specified according to customer needs, and which consists of a product definition module. Outputs from this system are, at a minimum, characterized by article codes (ACs), quantity to be assembled (Q), and production due dates (PDD). Moreover, functional requirements are also specified in this phase. When the final product is defined, component separation is performed according to a bill of material (BOM). Firstly, components are divided into stable (S), compulsory optional (CO) components, and voluntary optional (VO) components. This classification is important, especially at higher levels of the maturity model where variety-based complexity is a matter of major concern affecting the product and process design (Modrak and Soltysova 2018b). Requirements for the CO and VO components further face a make or buy decision, where they are divided into their own base production or ordered from a supplier. Subsequently, schedules for product manufacturing are generated. Then, based on information about component consolidation, detailed schedules for multi model assembly line(s) are calculated and provided to the product assembly system department. Finally, the product assembly process is triggered and managed. This phase mostly includes the performance of functional requirements.

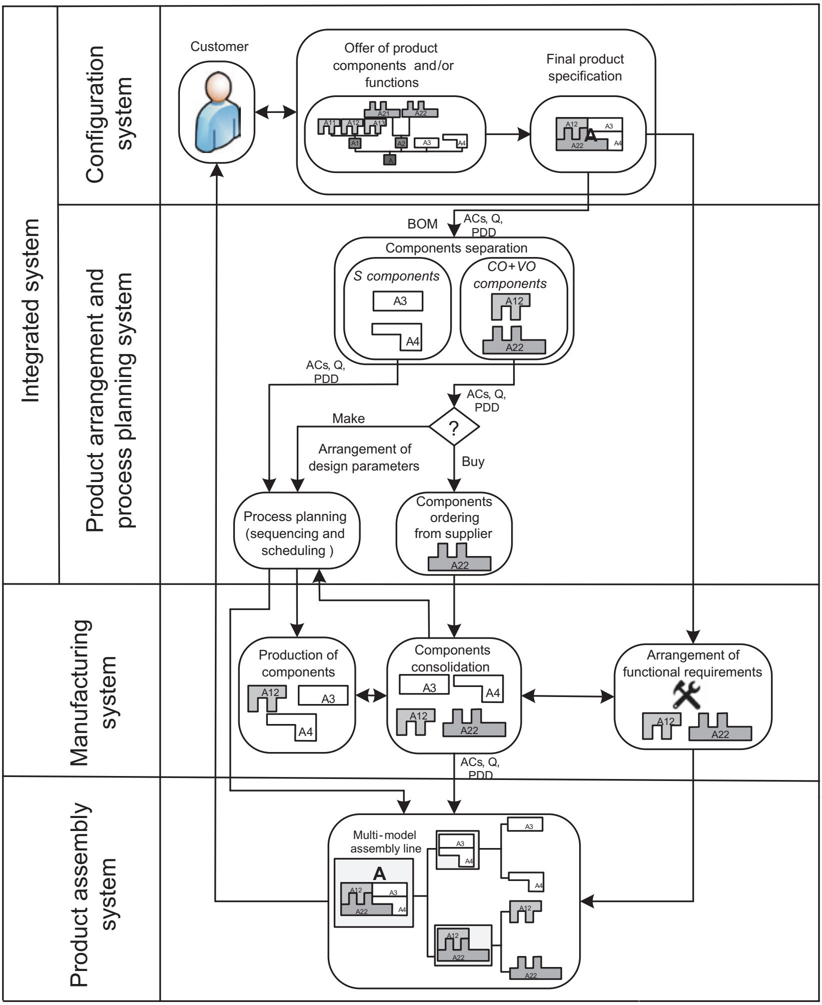

Fig. 8.7 Model of the relations between orders and manufacturing operations

8.7 Future Research Work and Conclusions

Analysis of the results obtained from the application of the QMM confirms and emphasizes that an effort of SMEs in the context of Industry 4.0 challenges has to also be dedicated to organizational and managerial aspects. For this purpose, theoretical concepts such as frameworks or maturity models can be useful to anticipate relevant directions and factors affecting the achievement of this strategic goal. Accordingly, and in line with this statement, this chapter offers a structured approach to carrying out self-assessment for Industry 4.0 implementation, and moreover, proposes the generic I4.0 RMM as the roadmap for helping companies to navigate them and understand their current state in the mass customization environment.

The literature review on existing approaches was mostly based on self-assessment by using a questionnaire with yes or no answers, and oriented towards the identification of a company's current state related to the maturity requirements. The proposed maturity models are focused on organizational and managerial aspects in terms of mass customization. While I4.0 QMM can be used for mapping the three domains: smart manufacturing, smart logistics, and organizational and managerial facets, the I4.0 RMM is dedicated to the readiness of organizational capabilities for mass customized manufacturing.

The given results will be used in our future work for the development of technical solutions and managerial methods that will enable managers to make better decisions for the digital transformation of SMEs from the current state to the targeted state. In this context, the generic conception of mass customized manufacturing based on the integration of a product configurator in process planning will be further developed. For example, it will be necessary to follow the development of marketing tools based on social networks and new communication channels. As is known, the connection of a product configurator with a Facebook site can facilitate not only social connections between existing and potential customers but also help in the codesign of activities (Gownder et al. 2011).

In spite of early skepticism about mass customization, which was seen as not very useful and as a contradictory concept, its penetration in different industries has become a reality. As was almost predicted, MC has become an imperative rather than a choice leading to sustainable success across business sectors (Piller 2010). However, wider acceptance of this strategy in individual industries will strongly depend on the availability of attainable digital manufacturing devices belonging to the smart manufacturing concept.

Appendix 8.1

Maturity levels of QMM in the Organizational and managerial domain

Category title	Level	Description of maturity level
Business strategy	L1	The organization does not have a formal strategy I4.0 as a part of the corporate strategy
	L2	Managers are convinced of the need to develop a strategy for I4.0
	L3	Managers work on a strategy for I4.0 focused on technological aspects
	L4	Business activities for technology change are aligned with company strategy
	L5	The strategy for I4.0 is more focused on people than on production technology
Business models related to product	L1	Earning income from the sale of standardized products
	L2	Groups of standardized products are shipped to different markets according to local needs
	L3	Possibility to customize the product based on group(s) of variant modules
	L4	Possibility to customize the product from a wide range of components
	L5	Mass personalization
Innovative culture	L1	Openness for digital technologies
	L2	Identification with the building of digital enterprise
	L3	Orientation in the development of intelligent technologies and products
	L4	Intelligent technologies and/or products are introduced
	L5	Optimization of intelligent technologies and products
Organizational production model	L1	Traditional approach by type of production type
	L2	Orientation on product modularization
	L3	Orientation on process modularization
	L4	Application of the organizational model of production for mass customized products
	L5	Optimization of the organizational production model for mass customization

Category title	Level	Description of maturity level
Knowledge management	L1	The organization does not have any formal knowledge management strategy (KM)
	L2	Managers are aware of the need to develop their own strategy KM
	L3	Managers develop and implement the KM strategy
	L4	Activities for creation and sharing of knowledge are in line with the KM strategy focused on technology and people
	L5	Activities for creating and sharing knowledge are more people-oriented than on technology. The sustainability of the established KM is permanently monitored

Appendix 8.2

Maturity levels of QMM in the Smart logistics domain

Category title	Level	Description of maturity level
Transport logistics	L1	Decentralized managed transport
	L2	Centralized managed transport
	L3	Predictive centralized transport. Ad hoc managed distribution
	L4	Predictive centralized transport. Optimized management of distribution
	L5	Use of autonomous vehicles
Outbound logistics	L1	Push management of the delivery process (in warehouses)
	L2	Order-based delivery process control
	L3	Order-based delivery process control with sales monitoring
	L4	Automatic control of the delivery process
	L5	Automatic delivery process management with prediction of future order
In-house logistics	L1	Use of manual means in inter-operational traffic
	L2	Use of manually operated trolleys in inter-operational traffic
	L3	Use of automatically guided trolleys in inter-operational traffic on defined routes
	L4	Use of automatically guided trolleys in inter-operational traffic on open production area
	L5	Management of autonomous trolleys through production facilities

Category title	Level	Description of maturity level
Inbound logistics	L1	Push management of the supply process (in warehouses)
	L2	Pull method for managing the supply process (JIT)
	L3	Pull method fot managing the supply process (JIT) provided by the retailer
	L4	Autonomous inventory management
	L5	Predictive inventory management
Warehouse management	L1	Use of manual devices for storage operations
	L2	Use of manually guided forklifts
	L3	Use of automated guided vehicle systems and automated storage systems
	L4	Use of automatic systems with links to superior enterprise management systems
	L5	Use of automatic and/or collaborative transport and storage trolleys

Appendix 8.3

Maturity levels of QMM in the Smart production domain

Category title	Level	Description of maturity level
Data processing in the production	L1	Conventional data processing methods (waybills, etc.)
	L2	Use of optical technologies for data processing (bar codes, etc.)
	L3	Use of radio frequency technologies for data processing (RFID)
	L4	Evaluating and using data for process management and planning
	L5	Use data (monitored in real-time) to automate planning and process management
Man to machine communication	L1	No exchange of information between machine and man
	L2	Using local user connections on the machine.
	L3	Centralized or decentralized monitoring and production control
	L4	Using mobile user interfaces
	L5	Enhanced virtual reality and assisted reality

Category title	Level	Description of maturity level
Machine to machine communication	L1	No exchange of information between machines
	L2	Connect devices using a bus
	L3	Machines have an industrial Ethernet interface (local computer network)
	L4	Machines have internet access.
	L5	Web interfaces and information exchange applications (M2M software)
ICT infrastructures in the production	L1	Exchange information via email/ phone
	L2	Central data servers in production
	L3	Internet portals for data sharing
	L4	Use of ICT to identify statuses in production (e.g., status of order)
	L5	Suppliers and/ or customers have access to a web-supported IS (MES)
Digitalization	L1	Basic level of digitization
	L2	Uniform digitization (horizontal)
	L3	Horizontal and vertical digitization
	L4	Full digitalization
	L5	Optimized full digitalization

Appendix 8.4

The questionnaire structure

No. of category	Category title	Current state	Future target
1	Business strategy	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐
2	Business models related to product	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐

No. of category	Category title	Current state	Future target
3	Innovative culture	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐
4	Organizational production model	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐
5	Knowledge management	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐	L1 ☐ L2 ☐ L3 ☐ L4 ☐ L5 ☐

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