Mapping Requirements and Roadmap Definition for Introducing I 4.0 in SME Environment

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Abstract. Industry 4.0 as a new manufacturing paradigm brings in a new wave of networked manufacturers and smart factories, which will determine future competitiveness of manufacturing companies. The aim for researchers should thus be to generate and optimize innovative solutions for different types of producers including SMEs in order to support them in meeting the challenges of Industry 4.0. The paper presents the readiness self-assessment method and roadmap model as a tools to secure a consistent implementation of technologies and devices supporting smart logistics and smart production. Proposed method has been applied by selected SMEs and it was proved that the model is easy to use in real production environment.

Keywords: Self-assessment · Industry 4.0 · Requirements · Smart production Smart logistics · Organizational models · Roadmaps

1 Introduction

Production technologies are in these days mostly affected by dynamical development of information and 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 innovation, and so on. 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 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* [1]. The main objectives of Industry 4.0 can be in a simple way summarized as the introduction of intelligent systems in production, logistics and e-business models. In the context of Industry 4.0 new information and communication technology (ICT) and web technologies act as enablers of smart, autonomous and self-learning factories. Presently, the growing number of factories is facing the challenges of even more individualized and customized products [2]. It induces a high manufacturing process complexity level because of various customer

S. Hloch et al. (Eds.): ICMEM 2018, LNME, pp. 183–194, 2019.
https://doi.org/10.1007/978-3-319-99353-9_20

requirements [3]. On the other hand, when the degree of customization is high, then possible incompatibilities between optional component types may cause serious problems such as customer dissatisfaction [4]. One possible way to eliminate or reduce the customer disappointment is eliminating infeasible configuration options, caused by incompatibilities between optional component types, within a product platform [5].

A great challenge for the future lies in the transfer of Industry 4.0 expertise and technologies in small and medium sized enterprises (SMEs). SMEs represent the backbone of the economy and have an enormous importance in the development programs of the European Union for strengthening the competitiveness of European enterprises. Although the high potential of Industry 4.0 in SMEs, the main limit lies in a lack of methodological frameworks for its implementation and application. Accordingly, presented research outputs aims to help in overcoming this gap through proposed solutions.

The next section of this paper is focused on the existing literature, which relates to proposed method. The third section describes the methodology of proposed method, in which three main areas of the I4.0 concept, namely, smart logistics, smart production, and organizational and managerial models are considered. The subsequent part of the paper shows the practical application of the requirements mapping on the experimental group consisting of 10 selected SMEs. The next section of the paper analyses and evaluates the obtained results from questionnaires according to the proposed methodology. Finally, concluding remarks are summarized.

2 Related Works

As obvious, enterprises can have different maturity models to identify company readiness, e.g., from viewpoint of new technologies, processes, organizational aspects, etc. Therefore, many various roadmaps were created to identify maturity levels of enterprise in diverse areas. Proposed model for enterprise self-assessment described in the following sub-section reflected experiences from existing literature. Specification of the five categories and the five maturity levels of smart logistics available in Table 2 was inspired from the UNITY Consulting and Innovation – via The Network Effect [6]. Leyh et al. [7], described requirements on information systems for smart production in the context of Industry 4.0. His experiences were used for specification of category 2.5 for the area of smart production described in Table 3. Anderl [8] proposed useful guiding principles for the implementation of Industry 4.0 in SMEs from the viewpoint of products and production. His ideas were used in specification of categories for smart production. The specification of the third area focused on organizational and managerial models and their categories was influenced by works of Agca et al. [9], Ibarra et al. [10], Kans et al. [11] and Ariaz-Perez et al. [12]. It would be possible to list other references, which indirectly contributed towards the development of the subject. Some of them, which recently presented related maturity and readiness models in terms of Industry 4.0 are compared in the Table 1.

Table 1. Compared existing related maturity and readiness models.

Author (Year)	Publication Title	Research Focus (domains of future changes)	Benefits	Disadvantages
R. Geissbauer, J. Vedso, S. Schrauf (2016) [13]	Industry 4.0 Building the digital enterprise	Blueprint for digital success – Map out (- focus on people - focus on culture to drive transformation - digital enterprise)	Statistics comparison	Focused only for digital data
T. Stock, G. Seliger (2016) [14]	Opportunities of Sustainable Manufacturing in Industry 4.0	Macro / Micro perspective of Industry 4.0 (human resources, product, process, organization, value chain, business model)	Horizontal and Vertical integration	General model with no closer specification
J. Ganzarain , N.Errasti (2016) [15]	Three Stage Maturity Model in SME's towards Industry 4.0	Framework for Industry 4.0 (roadmap, - business model, tailored industry, product analysis)	Process model towards Industry 4.0	No closer specification
D. Ivanov, B. Sokolov, M. Ivanova (2016) [16]	Schedule coordination in cyber-physical supply networks industry 4.0	A dynamic model to coordinate activities in cyber-physical supply chains in smart manufacturing concepts (collaboration, competencies, operation, resources)	Mathematical model, Generalized algorithm	Focused on Cyber- physical supply network
F. Chromjakova (2016) [17]	Flexible man-man motivation performance management system for Industry 4.0	Focused on the element of man position in the Industry 4.0 (process motivation, product motivation, human resources (personality), programmable machine, digitization)	Core scheme of man-man system, Survey oriented on the state of implementation and experiences with I4.0	Missing logistic, business model research
R. Y. Zhong , X. Xu, E. Klotz, Stephen T. Newman (2017) [18]	Intelligent Manufacturing in the Context of Industry 4.0: A Review	Intelligent manufacturing/ Cloud manufacturing /IoT (smart manufacturing, cyber physical system, information a communications technology, smart machine, human, machine collaboration, smart control	Focused on Big data and computing implementation	No Smart Logistic /Value chain research included
P.M. Singh, M.J van Sinderen, R.J Wieringa (2017) [19]	Smart logistics: An enterprise architecture perspective	Design architecture of smart logistic enterprise (logistic, integration of big data, smart planning)	Implementation of Methodology for smart logistic	Focused for logistic only
D.Chavarría-Barrientos, R. Batres, P.K. Wright, A. Molina (2017) [20]	A methodology to create a sensing, smart and sustainable manufacturing enterprise	Smart and Sensing Enterprise Reference Model (product model, digital manufacturing, sustainable manufacturing, manufacturing strategies (Lean manufacturing, mass production))	Action research Methodology	Methodology and sup being general
R. Kumar , E.Namapuraja (2017) [21]	Making Industry 4.0 Real – using the acatech I4.0 Maturity Index	Six dimensions that indicate increasing Industry 4.0 maturity levels (organization structure, organization culture, information system)	Overlook of organization structure, culture and information system	No business model and no logistic specification included
E. Hofmann, M. Rüsch (2017) [22]	Industry 4.0 and the current status as well as future prospects on logistics	A logistics-oriented Industry 4.0 application model (logistic, digital world, physical world)	Real examples, Industry 4.0 scenario	Focused just on logistic application model

3 Methodological Framework

The proposed readiness self-assessment method and roadmap model aims to identify readiness status and define future targets within the three main areas, namely [23]:

- smart logistics,
- smart production,
- and organizational and managerial models.

Each of these areas is divided into 5 related categories and each category include 5 levels to select from.

Mapping of innovative requirements of small and medium-sized enterprises in the context of the strategy Industry 4.0 consisted of the following steps:

- creation of the questionnaire;
- mapping of requirements;
- results processing.

3.1 Creation of the Questionnaire

Questionnaire method was chosen due to its advantages including increased speed of data collection, low or no cost requirements, and higher levels of objectivity in comparison with many alternative methods of data collection. The proposed questionnaire includes five categories, which were selected on the basis of maturity models and models of preparedness in mentioned literature as well as our own experiences for each of the three areas. Structure of questionnaire of each area and related category with defined 5 levels (L) (where L#1 is the lowest and L#5 is the highest) are described in Tables 2, 3 and 4.

3.2 Mapping of the Requirements

In this paper, mapping of the requirements will be demonstrated by using real information from multi-case study. The ten selected small and medium sized enterprises took part in mapping. Individually categories and their levels have been explained in details at the beginning of the workshop organized for this purpose. Moreover, descriptions of the maturity development levels of each category of the three areas were supported by graphic pictograms. Subsequently, companies' representatives separately identified the current and planned or required status for each area and the specific categories by the questionnaires described in the sub Sect. 3.1.

3.3 Results Processing

Answers in the questionnaires were processed in following way:

(a) **Determination of the order of significance of categories for all the three areas**. Each of the 5 categories in the given area was assigned by a level number L (from 1 to 5) according to how each company identified the current and planned states. These simple rules were as follows:

Table 2. Smart logistics maturity model.

Category	Level	Description of the maturity level
Transport logistics (1.1)	#1	Decentralized managed transport.
	#2	Centralized managed transport.
	#3	Predictive centralized transport. Ad hoc managed distribution.
	#4	Predictive centralized transport. Optimized management of distribution.
	#5	Use of autonomous vehicles.
Outbound logistics (1.2)	#1	Push management of the delivery process (in warehouses).
	#2	Order-based delivery process control.
	#3	Order-based delivery process control with sales monitoring.
	#4	Automatic control of the delivery process.
	#5	Automatic delivery process management with prediction of future orders.
In-house logistics (1.3)	#1	Use of manual means in inter-operational traffic.
	#2	Use of manually operated trolleys in inter-operational traffic.
	#3	Use of automatically guided trolleys in inter-operational traffic on defined routes.
	#4	Use of automatically guided trolleys in inter-operational traffic on open production area.
	#5	Management of autonomous trolleys through production facilities.
Inbound logistics (1.4)	#1	Push management of the supply process (in warehouses).
	#2	Pull way of managing the supply process (JIT).
	#3	Pull way of managing the supply process (JIT) provided by the retailer.
	#4	Autonomous inventory management.
	#5	Predictive inventory management.
Ware-house manage-ment (1.5)	#1	Use of manual devices for storage operations.
	#2	Use of manually guided forklifts.
	#3	Use of automated guided vehicle systems (AGVS) and automated storage systems.
	#4	Use of automatic systems with links to superior enterprise management systems.
	#5	Use of automatic and/or collaborative transport and storage trolleys.

Table 3. Smart production maturity model.

Category	Level	Description of the maturity level
Data pro-cessing in the produc-tion (2.1)	#1	Conventional data processing methods (waybills, etc.).
	#2	Use of optical technologies for data processing (bar codes, etc.).
	#3	Use of radio frequency technologies for data processing (RFID).
	#4	Evaluating and using data for process management and planning.
	#5	Use data (monitored in real-time) to automate planning and process management.
Man to machine commu-nication (2.2)	#1	No exchange of information between machine and man.
	#2	Using local user connections on the machine.
	#3	Centralized or decentralized monitoring and production control.
	#4	Using mobile user interfaces.
	#5	Enhanced virtual reality and assisted reality.
Machine to ma-chine commu-nication (2.3)	#1	No exchange of information between machines.
	#2	Connect devices using a bus.
	#3	Machines have an industrial Ethernet interface (local computer network).
	#4	Machines have internet access.
	#5	Web interfaces and information exchange applications (M2M softwares).
ICT infra-structures in the produc-tion (2.4)	#1	Exchange information via email / phone.
	#2	Central data servers in production.
	#3	Internet portals for data sharing.
	#4	Use of ICT to identify statuses in production (e.g. status of order).
	#5	Suppliers and/ or customers have access to a web-supported IS (MES).
Digitali-zation (2.5)	#1	Basic level of digitization.
	#2	Uniform digitization (horizontal).
	#3	Horizontal and vertical digitization.
	#4	Full digitalization (IoT).
	#5	Optimized full digitalization.

Table 4. Organizational and managerial maturity model.

Category	Level	Description of the maturity level
Business strategy (3.1)	#1	The organization does not have a formal strategy I4.0 as a part of the corporate strategy.
	#2	Managers are convinced of the need to develop a strategy for I 4.0.
	#3	Managers work on a strategy for I 4.0 focused on technological aspects.
	#4	Business activities for technology change are aligned with company strategy.
	#5	The strategy for I 4.0 is more focused on people than on production technology.
Business models related to product (3.2)	#1	Earning income from the sale of standardized products.
	#2	Groups of standardized products are shipped to different markets according to local needs.
	#3	Possibility to customize the product based on group(s) of variant modules.
	#4	Possibility to customize the product from a wide range of components.
	#5	Mass personalization.
Innova-tion culture (3.3)	#1	Openness for digital technologies.
	#2	Identification with the building of digital enterprise.
	#3	Orientation in the development of intelligent technologies and products.
	#4	Intelligent technologies and/or products are introduced.
	#5	Optimization of intelligent technologies and products.
Organi-zational produc-tion model (3.4)	#1	Traditional approach by type of production type.
	#2	Orientation on product modularization.
	#3	Orientation on process modularization.
	#4	Application of the organizational model of production for mass customized products.
	#5	Optimization of the organizational production model for mass customization.
Knowled ge man-agement (3.5)	#1	The organization does not have any formal knowledge management strategy (KM).
	#2	Managers are aware of the need to develop their own strategy KM.
	#3	Managers develop and implement the KM strategy.
	#4	Activities for creation and sharing of knowledge are in line with the KM strate-gy focused on technology and people.
	#5	Activities for creating and sharing knowledge are more people-oriented than on technology. The sustainability of the established KM is permanently monitored.

- If the company only identified the current state without the request to change (e.g. level in current and planned state is the same), then the Rate of the change (R) was assigned to this category as $R = 0$;
- if the company identified the request to change, then $R = 1$. Since the change can be expressed over the interval (1, 5) from one level change to a change of five levels, each request has been assigned a Weighting value of W. Weighting values based on the level of change, while change in the range of one level equals 1, 2; of two levels equals 1, 4; of three levels equals 1, 6; of four levels equals 1, 8 and of five levels equals 2. The resulting Value for each category was determined by the equation:

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

  Subsequently, the order of significance has to be compiled for each category and for each of the three areas.

  Note: If values V are significantly different from each other, it is advisable to use Pareto analysis to select important and non-essential categories. If the differences between the values V are minimal, then all categories have to be taken into account and only the order of their significance is determined.

(b) **Identification of requirements.** The requirements to change from current state to expected state for each category were identified (summarily for 10 SMEs) in two phases:

1. Defining transitions from current states to required states is based on:
   - Enumeration of the Average current level (CL_A) for each category. The average value is determined using the arithmetic mean from 10 values of level numbers:

$$CL_A = \frac{\sum_{i=1}^{10} L_i}{10}, \tag{2}$$

   - and enumeration of the Average required level (RL_A) for each category. It is determined analogically:

$$RL_A = \frac{\sum_{i=1}^{10} L_i}{10}. \tag{3}$$

   Then, difference between these two states defines the summarized requirement for a change from a current level to a required level (for example, from the level 2 to level 4).

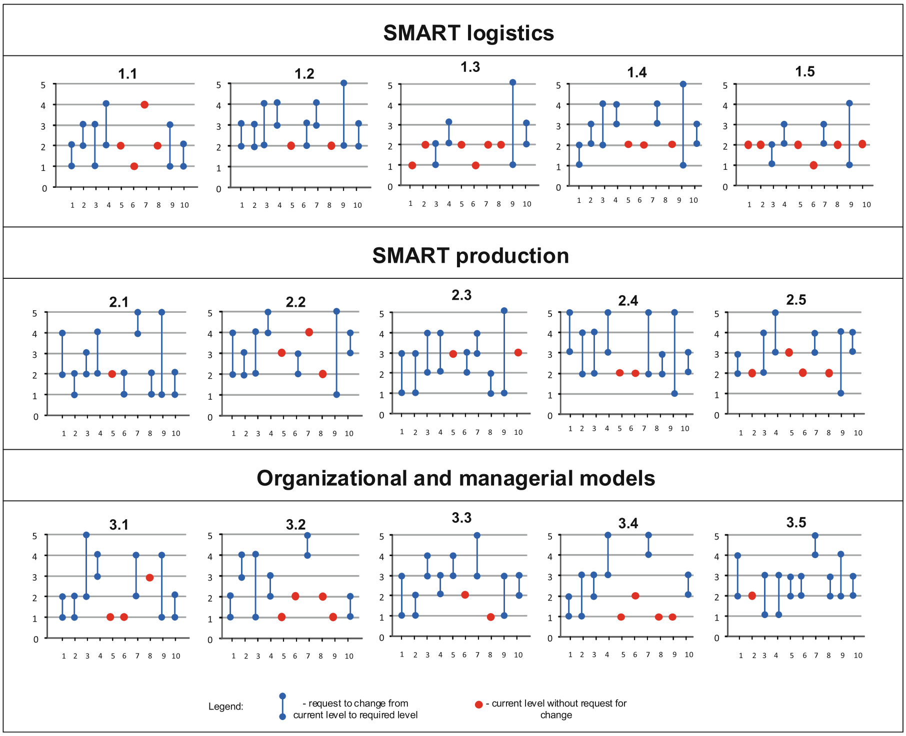

Fig. 1. Results of mapping of individual requirements for smart logistics, smart production, and organizational and managerial models.

2. Content specification of transitions from current level to required level.

The output of this method is roadmap definition describing the transition specification from the current state to required state, i.e. identifying of innovative requirements for SMEs in the context of strategy Industry 4. 0 as shown in Fig. 1.

4 Description of Obtained Results

Applying the self-assessment method and roadmap model from Sect. 3, results of mapping of individual requirements of the 10 companies are graphically depicted in the Fig. 1.

The category importance values *V* for the three areas were calculated in accordance with Sub-Sect. 3 of the methodology. The results of *V* and cumulated values in % are listed in the Table 5 according to their order of category of significance (OCS).

Table 5. Determination of the order of category of significance for all the areas.

Areas	SMART production					SMART logistics					Organizational and managerial models				
OCS	1.2	1.4	1.1	1.3	1.5	2.1	2.4	2.3	2.2	2.5	3.5	3.3	3.1	3.2	3.4
V	10, 2	9, 2	7, 8	5, 4	5, 2	11, 8	11, 4	11	9, 4	8	11, 6	10, 2	9, 4	7, 6	7, 6
%	27	51	72	86	100	23	45	66	85	100	23	46	66	83	100

Differences in values *V* for all three areas are minimal, so it is inappropriate to use the Pareto principle to determine important and irrelevant categories. For this reason, values will only be used to determine the order of category significance.

In the next step, there were calculated the average current and required levels for each category of each three areas in order to identify the requirements of small and medium-sized enterprises in the context of the strategy Industry 4.0. The obtained results are graphically shown in Fig. 2.

As can be seen from the Fig. 2, the most significant requirements were identified for the area of smart production, the next important area is smart logistics and the least significant is area of organizational and managerial models.

In order to validate obtained results from population sample represented by 10 SMEs (subjects –S) by asking the questions, the overall internal consistency of the questionnaire can be measured by Cronbach's alpha [24]. For this purpose, the obtained data were arranged into Table 6.

Subsequently, Cronbach's alpha coefficients were separately calculated for the current states and the required states by using the formula [25]:

$$\alpha = \left(\frac{k}{(\mathrm{k}-1)}\right) * \left(1 - \left(\frac{\sum s_i^2)}{s_t^2}\right)\right), \tag{4}$$

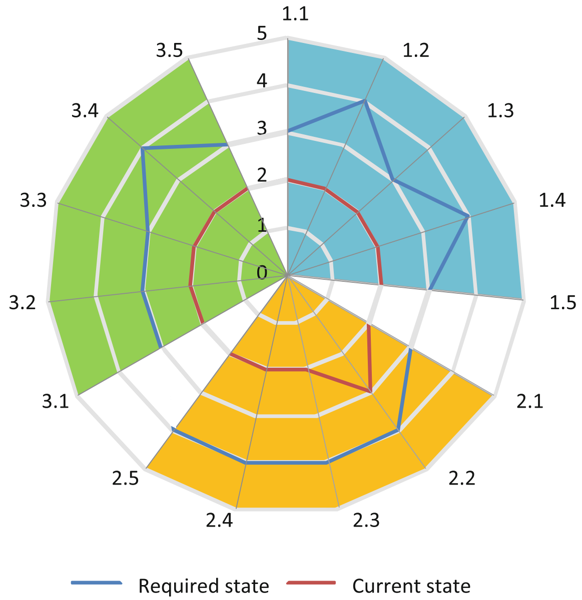

Fig. 2. Spider graph of differences between current states and required states.

Table 6. 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

(white) - Current state (grey) - Required state where, k = number of items - questions in questionnaire (Q), S_i = SD of ith item, and $S_t = SD$ of sum score.

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

5 Conclusions

Summarizing the obtained results, it can be expected that effort of SMEs related with Industry 4.0 challenges will be focused:

(a) in *the production domain* especially on:

- use of RFID technologies for data processing,
- using mobile user interfaces,
- using machines with internet connection,
- use of ICT to identify statuses in the production,
- introduction of IoT into the production;

(b) in *the logistics domain* especially on:

- implementing of automatic control into delivery processes,
- introduction of autonomous inventory management;

(c) in *the organizational and managerial domain* especially on:

- application of the organizational models of production for mass customized products.

Moreover, the study presented in this paper offered possible generic Industry 4.0 maturity model as self-assessment tool to provide companies to help them understand their current state in the field of Industry 4.0.

The given results will be in our future work used for development of technical solutions and managerial methods for transitions from the current technical/technological states to the required states.

Acknowledgement. This paper has been supported by the project with acronym SME 4.0 and titled as "SME 4.0 - Smart Manufacturing and Logistics for SMEs in an X-to-order and Mass Customization Environment" with funding received from the European Union's Horizon 2020 research and innovation program under the H2020-EU.1.3.3, Project ID: 734713 and by VEGA project Nr. 1/0419/16 granted by the ME of the Slovak Republic.

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