TRANSITION OF SMES TOWARDS SMART FACTORIES: A MULTI-CASE SURVEY

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Abstract: This paper aims to map the current state and future expectations of small and medium-sized enterprises (SMEs) from Industry 4.0 implementation. For the given purpose, a readiness self-assessment survey method was developed and applied for groups of respondents from selected SMEs. This survey focuses on the following three main areas: smart manufacturing, smart logistics, and platform based business models. Each of these areas consists of five sub-areas for which maturity levels are defined. The novelty of the proposed maturity model lies in identifying current maturity levels, and maturity levels where companies would like to be by choosing from the options. The results of the survey showed that, of the three areas mentioned, the highest attention is paid to manufacturing areas, while digital platform business models are of the least interest to SMEs.

Key words: Industry 4.0, requirements, smart manufacturing, smart logistics, digital business models

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Introduction

A smart factory presents, in its essence, digitized manufacturing facility that uses connected devices such as sensors, production machines and systems to continuously collect and share data. This data is then used to improve processes or to help make proper decisions as well as address any issues that may arise. Thus, it is quite obvious that the phenomenon of industrial digitalization is growing in popularity as it offers wide opportunities for technological and business development of enterprises (Fitzgerald et al. 2014 and Kane et al. 2015). In this context, it is useful to point out that digitalization as a term or concept should not be considered synonymous with digitization, which is rather thought of as a

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precursor of digitalization (Ross, 2017). This new wave of so called intelligent manufacturing is promoted in Germany under the aegis of Industry 4.0 (Kagermann et al. 2013), while similar approaches to adoption of intelligent tools and IoT to manufacturing are covered in the United States under umbrellas of The Smart Manufacturing Leadership Coalition (Workshop summary report, 2011), and The Industry IoT Consortium (Hardy, 2014). Moreover, other major industrial countries, e.g., People's Republic of China, Japan or The Republic of Korea reflected these initiatives by establishing comparable national programs (Nishioka, 2015; Park, 2015). For easier reading, hereinafter above mentioned approaches will be denoted as Industry 4.0 (I4.0).

Digital technologies are, in general, exploited in a form of digital artefacts, digital platforms, and digital infrastructures (Nambisan, 2017). Digital artefacts include different types of items, such as ad-hoc databases, documents and formal systems that can be effectively used, e.g., in development and/or innovation of industrial products and manufacturing processes (Ciriello, 2019). This term simply covers a wide range of software-based products and objects using digital technology for data collection, processing and/or transmission. Digital business platforms in a form of online businesses for interaction between suppliers and customers are becoming the backbone of the circular economy (Soltysova and Modrak, 2020) as they reducing transaction costs for users and production costs for business actors (Rangaswamy, 2020). Moreover, this business practice blurs the boundaries between technology and management (Verma et al., 2012), and shows how firms face new societal challenges like global sustainable development, green economy, and green growth. Digital infrastructure includes technologies such as IoT, 5G networks, cloud computing, data analytics, social media, open standards, and others. These technologies are categorized as external enablers of digital entrepreneurship that allow effective communication, collaboration, and exchanging information between the different actors involved. Moreover, they help to innovate of entrepreneurship by facilitating interactions between individuals and enterprises (Aldrich, 2014). For example, cloud computing, and data analytics can be effectively used for testing of novel business models involving a larger set of potential customers (Hatch, 2013). Therefore, there is no doubt that a great challenge for the future lies in a large involvement of SMEs in digitalization efforts. Although there is a large body of evidence about advantages of digitalization showing that, e.g., it brings more customers from new markets, one of the main obstacles on this way seems to be a lack of supportive guidelines for implementing this new strategy.

In order to help respond to this challenge, this paper aims to explore current and future expectations of SMEs in implementing digital technologies to their business models. For that purpose, three maturity models were developed, and readiness self-assessment survey method was applied for groups of respondents from selected SMEs. Finally, at the end of the article, obtained results of this mapping are comprehensively interpreted in graphical form, and pertinent comments on them are provided.

Methodological Framework

In this article a rigorous literature review is firstly conducted to provide an overview about the recent research on digitalization in manufacturing processes, logistics operations, and platform-based business models. Then, development trend analysis for the three areas is performed using a bibliometric method. Subsequently, maturity models for the three areas where developed and finally, the questionnaire survey method was carried out. The conceptual framework of this article with its steps and components is depicted in Figure 1.

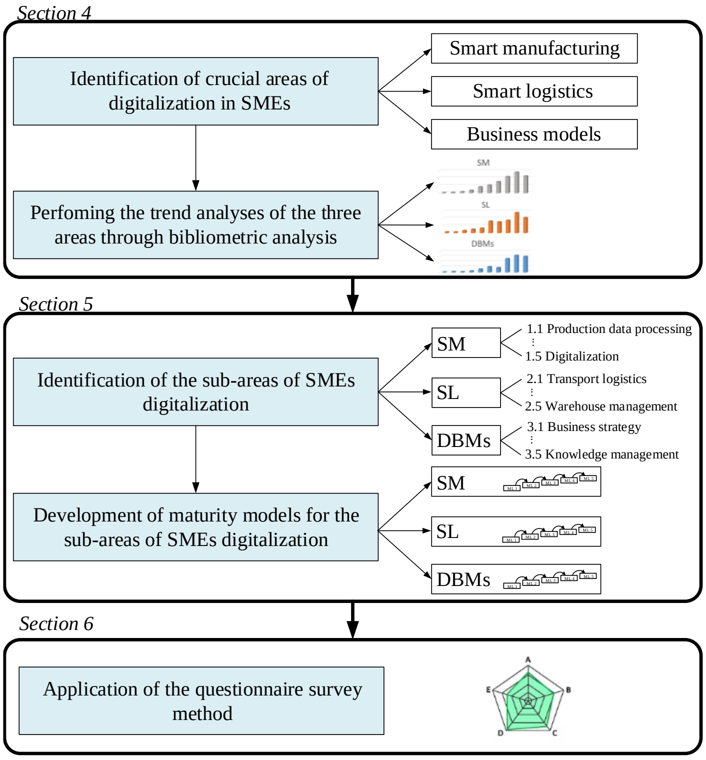

Figure 1: A methodological framework

Related Works

Industry 4.0 is a widely investigated topic in existing literature, and its journey is not just about technological prerequisites but also about what contributes to the successful transition of companies towards a more competitive position in the global marketplace. Moreover, it is about understanding that the use of advanced technologies, which are crucial part of smart manufacturing, opens wide range of possibilities for variety of modern logistics concepts covered under the term smart logistics (Uckelmann, 2008), and novel digital-based business models (Kosasi, 2019). It is therefore understandable that digital-based companies have an advantage to more traditional manufacturing-based businesses, which lies in the simpler embracing modern strategies such as, e.g., crowdsourcing (Hossain, 2015), mass customization (Modrak, 2017). The readiness of SMEs for the implementation of Industry 4.0 strategy is frequently assessed using the readiness models and/or maturity models (Pacchini et al., 2019; Matt et al., 2021). Because of the close interconnectedness of the two models (Mittal et al., 2018), it is sensible to see them as integrally related, and therefore, hereinafter referred to as maturity models (MMs).

Generally speaking, there are many literature sources dealing with MMs, their development, analyses, comparisons and applications in the context of Industry 4.0 readiness assessment. Those sources can be divided into the several categories, e.g., literature reviews, guides and/or procedures for MMs development, and applications of MMs. Reviews papers or state of the art articles are exploring existing MMs from various viewpoints. For example, Jinkang et al. (2011) provide systematic review of existing maturity models from the key process areas perspective. The goal of their paper was to identify main activities, which are used to achieve higher maturity level when implementing I 4.0. Dikhanbayeva et al. (2020) analyzed selected I4.0 MMs based on the several core design principles with the aim to help involved stakeholders to obtain better understanding of the digital transformation benefits. Validation approaches to assess applicability of digital maturity models to SMEs have been outlined by authors such as Mittal et al. (2018) and Williams et al. (2022). Several studies were dedicated to assess the readiness of SMEs for smart manufacturing adoption (see, e.g., Sheen et al., 2018; Shukla et al., 2024; Grufman et al., 2020; Dima et al., 2010). Some of them were focused on technological and economical aspects (Semeraro et al., 2023; Kovács and Kot, 2016; Frank et al., 2019; Man et al., 2011). Another studies have reported approaches to map the present situation to obtain a valuable information regarding I4.0 preparedness (Bastos et al., 2021). Furthermore, there are also studies on smart logistics maturity models aimed to assess SMEs readiness in adapting the I4.0. (Chaopaisarn and Woschank, 2021; Sternad et al., 2018; Facchini et al., 2020; Oleśków-Szłapka et al., 2019). Here, the most relevant domains of interest can be mentioned, such as purchase logistics, distribution logistics, material flow and information flow (Modrak et al., 2012). Finally, it is worth mentioning that several research teams have proposed original approaches (Holzner et al., 2032; Lestantri et al., 2022; Motjolopane and Chanza, 2023) to assess SMEs readiness towards digitalization of their businesses. Some of those papers in this context analyzed organization aspects regarding the digital transformation (Aras and Büyüközkan, 2023; Colli et al., 2019; Simetinger and Basl, 2022), and other ones investigated relation between digital business models and smart manufacturing concepts

(Schumacher et al., 2019; Vasconcellos et al., 2021; Soares et al., 2021; Kolla et al., 2019).

Critical Areas of Smartness in SMEs

The preceding literature analysis, both explicitly and implicitly, showed that the im-pact of global digitalization on SMEs is most pronounced in the three areas, namely: manufacturing, logistics and business models. To assess the current and possible future developments in the identified areas of digitalization in SMEs, the bibliometric analysis is further employed to provide factual and objective information about objects of interest.
For given purpose data were collated by searching Scopus database using the following search terms: “smart logistics” and SMEs, “smart manufacturing” and SMEs, and “digital business models” and SMEs. The obtained data from the search engine are firstly explored for all the years. These data are depicted in Table 1 in descending order.

Table 1. Number of publications for all years

Search terms	Number of publications in Scopus database)
“Smart manufacturing” and SMEs	4 333
“Digital business models” and SMEs	984
“Smart logistics” and SMEs	377

Subsequently, these data were classified by the filter “Year of publication”, while the years from 2014 to 2023 were applied for this purpose. The obtained results the numbers of publications for all the three areas published in Scopus database are graphically depicted in Figure 2.

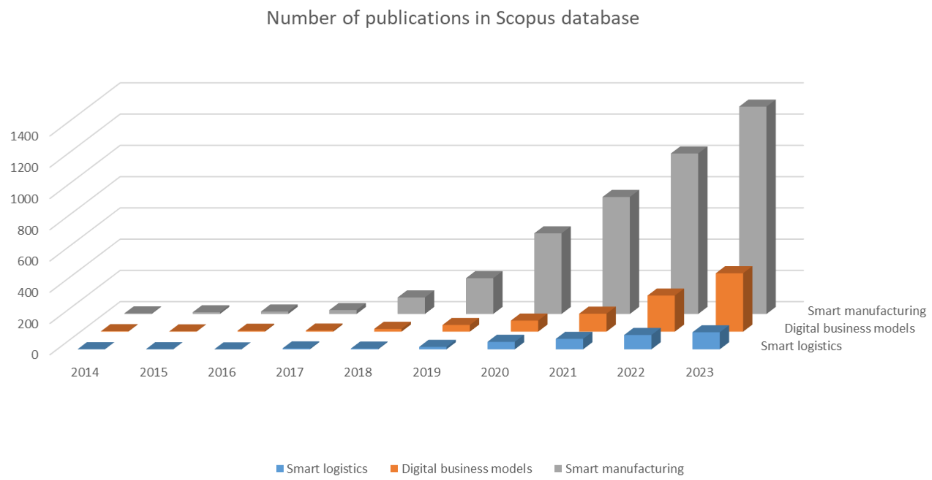

Figure 2: Comparison of development trends among the three areas

As can be seen from this graph, the numbers of research publications during the recent ten years differs among the analyzed areas. As it is known there is a reciprocal relationship between manufacturing and logistics, but in the Industry 4.0 context, more emphasis is placed on smart manufacturing area, than smart logistics area. This is in line with the finding that smart manufacturing is the most important part of the I 4.0 (Grefen et al., 2022). Moreover, the developing tendency of smart manufacturing popularity has a growing character, which testifies to the topicality of the given issue. It can also be seen from the graph in Figure 2 that the digitization of business processes is also becoming a relevant area in transition of SMEs towards smart factories. The results of this trend analysis show that that in all three analyzed areas a significant upward trend was recorded in the period 2019 – 2023.

Definition of the Sub-areas of SMEs Digitalization and Their Maturity Levels

Each area contains five sub-areas, 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. The five sub-areas for each area are listed in table below.

Table 2. The three main areas and its sub-areas

Smart manufacturing	Smart logistics	Digital business models
1.1 Production data processing	2.1 Transport logistics	3.1 Business strategy
1.2 Man to machine communications	2.2 Outbound logistics	3.2 Digital business models related to product
1.3 Machine to machine communication	2.3 In-house logistics	3.3 Innovation culture
1.4 ICT infrastructures in the production	2.4 Inbound logistics	3.4 Organizational production model
1.5 Digitalization of Business processes	2.5 Warehouse management	3.5 Knowledge management

Each area and related sub-area have defined five maturity levels, where Level#1 is the lowest and Level#5 is the highest, as can be seen in Tables 3 - 5.

Table 3. Smart manufacturing maturity model and its maturity levels

Maturity levels/ Sub-areas	Level#1	Level#2	Level#3	Level#4	Level#5
1.1	Conventional data processing methods (waybills, etc.).	Use of optical technologies for data processing (bar codes, etc.).	Use of radio frequency technologies for data processing (RFID).	Evaluating and using data for process management and planning.	Use data (monitored in real-time) to automate planning and process management.
1.2	No exchange of information between machine and man.	Using local user connections on the machine.	Centralized or decentralized monitoring and production control.	Using mobile user interfaces.	Enhanced virtual reality and assisted reality.
1.3	No exchange of information between machines.	Connect devices using a bus.	Machines have an industrial Ethernet interface (local computer network).	Machines have internet access.	Web interfaces and information exchange applications (M2M software).
1.4	Exchange information via	Central data servers in	Internet portals for data sharing.	Use of ICT for	Suppliers and/ or customers

	email / phone.	production.		monitoring states in production.	have access to a web-supported IS (MES).
1.5	Basic level of digitization.	Uniform digitization.	Horizontal and vertical digitization.	Full digitalization (IoT).	Optimized full digitalization.

Table 4. Smart logistics maturity model and its maturity levels

Maturity levels/ Sub-areas	**Level#1**	**Level#2**	**Level#3**	**Level#4**	**Level#5**
2.1	Decentralized managed transport.	Centralized managed transport.	Predictive centralized transport. Ad hoc managed distribution.	Predictive centralized transport. Optimized management of distribution.	Use of autonomous vehicles.
2.2	Push management of the delivery process (in warehouses).	Order-based delivery process control.	Order-based delivery process control with sales monitoring.	Automatic control of the delivery process.	Automatic delivery process management with prediction of future orders.
2.3	Use of manual means in inter-operational traffic.	Use of manually operated trolleys in inter-operational traffic.	Use of automatically guided trolleys in inter-operational traffic on defined routes.	Use of automatically guided trolleys in inter-operational traffic on open production area.	Management of autonomous trolleys through production facilities.
2.4	Push management of the supply process (in warehouses).	Pull way of managing the supply process (JIT).	Pull way of managing the supply process (JIT) provided by the retailer.	Autonomous inventory management.	Predictive inventory management.
2.5	Use of manual devices for storage operations.	Use of manually guided forklifts.	Use of automated guided vehicle systems (AGVS)	Use of automatic systems with links to	Use of automatic and/or collaborative

		and automated storage systems.	superior enterprise management systems.	transport and storage trolleys.

Table 5. Digital business maturity model and its levels

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

	and people.

Application of Questionnaire Survey Method

The group of representatives of ten SMEs from the manufacturing sector with a broader international operating footprints were participated in this multi-case survey. Their role in the survey was to identify current maturity levels they are in the given sub-areas, and maturity levels where they would like to be. Subsequently, the identified levels were integrally processed in order to interpret them in a comprehensive way. For this purpose, a radar chart was used (see Figure 3), in which the articulated expectations regarding the changes from the current states to the indented states for each sub-area are presented as the averages of the current levels and the averages of the intended levels - both rounded to the nearest integers.

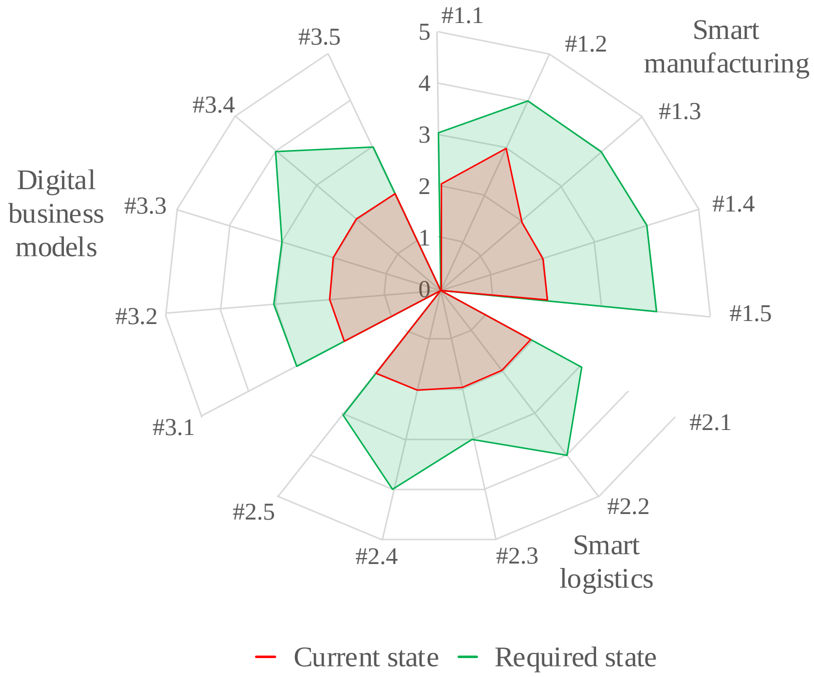

Figure 3: Radar chart of differences between current states and required states

From Figure 3 one can see that the area of Smart Manufacturing is perceived by the respondents as more important than both Smart Logistics and Digital Business Models domains. In other words, according to practitioners, having a strong internal manufacturing infra-structure is the key to future success. Moreover, the finding that Smart Manufacturing area is perceived by SMEs as more important among the three realms corresponds with the result of the bibliometric search shown in Figure 2.

To categorize the sub-areas within the areas according to their importance from the view of the respondents, the following formula has been used to enumerate significance number (SN):

$$SN = \sum_{i=1}^{10} R_i \cdot W_i, \qquad (1)$$

where R is the rate of the change determined as follows. If a company is considering a change of status in a given sub-area, then R = 1. Otherwise, R = 0, although this does not mean that the sub-area itself is insignificant, but it indicates that it is not subject to change and is therefore irrelevant from the point of view of the research objectives. W is the weighting value expressed as a transition distance from the current state to the intended state according to the rules shown in Table 6.

Table 6. Weighting values

Transition distance	W
the range of one level	1,2
the range of two levels	1,4
the range of three levels	1,6
the range of four levels	1,8
the range of five levels	2

Subsequently, the order of significance (OoS) of the sub-areas has been determined based on the significance number as shown in Table 7, and the ordered sub-areas are graphically depicted in Figure 4.

Table 7. Determination of the order of sub-area of significance for all the areas

Areas	Smart manufacturing					Smart logistics					Digital business models				
OoS	1.1	1.4	1.3	1.2	1.5	2.2	2.4	2.1	2.3	2.5	3.5	3.3	3.1	3.2	3.4
V_s	11,8	11,4	11	9,4	8	10,2	9,2	7,8	5,4	5,2	11,6	10,2	9,4	7,6	7,6

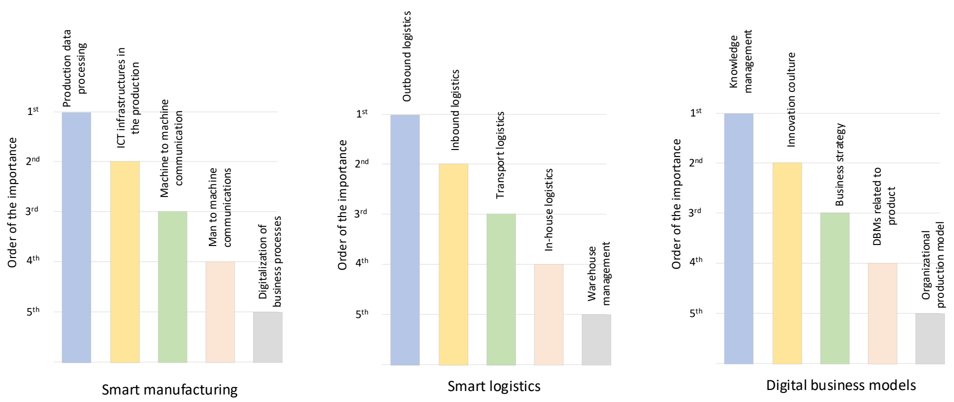

Figure 4: Order of importance in between the three areas

By this metrics and the graphical interpretations of the results one can prioritize which sub-area within given area is to be executed first considering its potential to bring the expected effect.

Statistical Values Validation

The overall internal consistency of the questionnaire data (the answers of the population sample represented by ten groups of respondents R1 to R10) will be further measured by the two methods for estimating reliability, namely: The McDonald’s omega (ω) coefficient, and the Cronbach’s alpha (α) coefficient. Input data to enumerate reliability using the both coefficients are available in in Table 8.

Table 8. Input data for calculations of Cronbach’s alpha and McDonald´s omega coefficients

Current level	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**	**Q13**	**Q14**	**Q15**
R1	2	2	1	3	2	1	2	1	1	2	1	1	1	1	2
R2	1	2	1	2	2	2	2	2	2	2	1	3	1	1	2
R3	2	2	2	2	2	1	2	1	2	1	2	1	3	2	1
R4	2	4	2	3	3	2	3	2	3	2	3	2	2	3	1
R5	2	3	3	2	3	2	2	2	2	2	1	1	3	1	2
R6	1	2	2	2	2	1	2	1	2	1	1	2	2	2	2
R7	4	4	3	2	3	4	3	2	3	2	2	4	3	4	4
R8	1	2	1	2	2	2	2	2	2	2	3	2	1	1	2
R9	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2
R10	1	3	3	2	3	1	2	2	2	2	1	1	2	2	2
Required level	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**	**Q13**	**Q14**	**Q15**
R1	4	4	3	5	3	2	3	1	2	2	2	2	3	2	4
R2	2	3	3	4	2	3	3	2	3	2	2	4	2	3	2
R3	3	4	4	4	4	3	4	2	4	2	5	4	4	3	3
R4	4	5	4	5	5	4	4	3	4	3	4	3	3	5	3
R5	2	3	3	2	3	2	2	2	2	2	1	1	4	1	3
R6	2	3	3	2	2	1	3	1	2	1	1	2	2	2	3
R7	5	4	4	5	4	4	4	2	4	3	4	5	5	5	5
R8	2	2	2	3	2	2	2	2	2	2	3	2	1	1	3
R9	5	5	5	5	4	3	5	5	5	4	4	1	3	1	4
R10	2	4	3	3	4	2	3	3	3	2	2	2	3	3	3

Subsequently, McDonald's omega coefficients were separately calculated for the current states and the intended states using the formula (McDonald 1999):

$$\omega = \frac{\left(\sum_{j=1}^{k} \lambda_j\right)^2}{\left(\sum_{j=1}^{k} \lambda_j\right)^2 + \sum_{j=1}^{k} \psi_j{}^2}, \tag{2}$$

where λ_j is factor pattern loading for item j; k is the number of items; Ψ_j – is unique variance of item j.

Cronbach's alpha coefficients were enumerated in same way as the previous coefficient by using the formula (Machin et al. 2007):

$$\alpha = \left(\frac{k}{(k-1)}\right) * \left(1 - \left(\frac{\sum s_i^{2})}{s_t^{2}}\right)\right), \tag{3}$$

where k is the number of items (answers of respondents) - questions in questionnaire (Q), Si is standard deviation of i^{th} item, and S_t is standard deviation of the sum score.

Both the coefficients range from zero to one exclusively, where zero indicates that there is no correlation between the items at all. Obtained vales were as follows:

McDonald's omega coefficient for the current state equals 0.865, and for the intended state its value is 0.91. Cronbach's alpha coefficient for the current state α = 0.92, and for the intended state α = 0.9. Then, based on a commonly accepted rule, it can be stated that internal consistency of the data is very satisfactory.

Discussion

Even though the brief literature review showed that maturity models related to digitalization of SMEs are relatively intensively treated by researchers, it is still sensible to generate complementary ones as presented here in Tables 3 - 5. This is because some new MMs can bring further insight into the developing suitable methodologies for transition towards digitalization of SMEs. To summarize all pertinent findings of this research, it can be stated that through the proposed questionnaire method, it was revealed that an effort of SMEs in implementation of Industry 4.0 in manufacturing domain is mostly focused on:

- use of RFID technologies for data processing,
- adaptation of mobile user interfaces,
- use of machines with embedded IoT sensors,
- use of ICT for monitoring states in the production,
- implementation of IoT into the production.

Further, it can be concluded that the main interest of SMEs regarding implementation of I 4.0 in in logistics domain and related targets to be achieved in the future lies in:

- implementing of automatic control into delivery processes,
- and in introduction of autonomous inventory management.

As regards to digitalization in the area of business models the main focus of SMEs is on application of the organizational models of production for mass customized products. Based on the obtained Spider graph from Figure 3, the most significant expectations were identified for the smart manufacturing area. Smart logistics has been identified as the next important area, and digital business models were recognized as the least significant category that needs attention.

When analyzing the obtained results related to sub-areas within the three areas, one can see that managers consider:

- man to machine communication as the critical domain in implementing elements of I 4.0 into manufacturing activities,
- transport logistics as the most powerful way to increase efficiency of business processes,
- knowledge management as important tool for development of platform based business models, since knowledge management helps to manage information and resources more effective.

Finally, it is hoped that the presented results can serve to identify key challenges in order to facilitate the transition to smartness of SMEs.

When comparing the results with conclusions of similar studies, it is possible to say that the work by Rauch et al. (2020) emphasized the need of introduction of digital technologies for business processes. In addition, Jung et al. (2021) come to the conclusion that digital innovations in manufacturing processes are perceived by SMEs as a priority area in the transformation of a companies into smart ones.

Conclusion

Summarizing the survey results, it can be stated that small and medium-sized enterprises companies adequately respond to the challenges of I4.0 that are related to manufacturing processes and logistics. It probably results from the fact that managers pay more or less continuous attention to innovations in production and logistics in the belief that it brings an immediate effect, even if often only of an incremental nature. On the other hand, it is rather a paradox that companies are not inclined to relatively easily implemented platform-based business models which often result in disruptive innovations. This is difficult to explain this fact by anything other than inertia of thinking and fear of change.

Limits of this survey are principally of two natures. First, the results provide only a statistical estimate of reality based on sample data, and therefore are subject to error. Second, considering that the survey was goal-oriented, the obtained results represent a certain reduction of all important areas that need to be taking into account in transition-journey of SMEs towards smart factories.

The given results can be in further effort used for development of managerial tools and technical solutions to achieve the expected levels of maturity from Industry 4.0 perspective.

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PRZEJŚCIE MŚP W KIERUNKU INTELIGENTNYCH FABRYK: WIELOSTUDIUM PRZYPADKÓW

Streszczenie: Niniejszy artykuł ma na celu zmapowanie obecnego stanu i przyszłych oczekiwań małych i średnich przedsiębiorstw (MŚP) związanych z wdrożeniem Industry 4.0. W tym celu opracowano i zastosowano metodę samooceny gotowości w formie ankiety dla grup respondentów z wybranych MŚP. Ankieta ta koncentruje się na następujących trzech głównych obszarach: inteligentna produkcja, inteligentna logistyka oraz modele biznesowe oparte na platformach. Każdy z tych obszarów składa się z pięciu podobszarów, dla których zdefiniowano poziomy dojrzałości. Wyniki ankiety wykazały, że spośród trzech wymienionych obszarów największą uwagę przywiązuje się do obszarów produkcji, podczas gdy modele biznesowe oparte na platformach cyfrowych cieszą się najmniejszym zainteresowaniem MŚP.

Słowa kluczowe: Industry 4.0, wymagania, inteligentna produkcja, inteligentna logistyka, cyfrowe modele biznesowe