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INDUSTRY 4.0 IMPLEMENTATION FACTORS FOR AGRI-FOOD AND MANUFACTURING SMEs IN CENTRAL AND EASTERN EUROPE

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Abstract

In partnership with the project "Possibilities and barriers for Industry 4.0 implementation in SMEs in V4 countries and Serbia" - funded by the Visegrad Fund, the authors conducted a survey with 124 small and medium enterprises (SMEs) in Central and Eastern Europe. Respondents (middle and top managers) from Bulgaria, Serbia, Hungary, Poland, Slovakia, and the Czech Republic were questioned about strategic factors affecting digitalization. We analyze theoretical factors based on literature review and if they are valid in the managerial context, not only for manufacturing, but also for the agri-food sector, where digital transformation (Agriculture 4.0) is considered to be in its infancy. Results indicate 21 variables that were aggregated to form five (5) strategic factors (Leadership, Management Strategy, Organizational culture, Business environment and Circular economy) with key importance for Industry 4.0 implementation in the organizations. The comparison based on Exploratory Factor Analysis between the manufacturing and agri-food sector results in statistical differences for all five factors. This study contributes to the management literature, and the identified factors can guide companies to develop a business model to be implemented in SMEs companies in their digital transition.

Keywords: Industry 4.0, SMEs, digitalization, agri-food sector, smart manufacturing, strategic factors, survey

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1. INTRODUCTION

In 2011, Europe joined the so-called Fourth Industrial Revolution as part of an institutional EU strategy to promote the digitalization of manufacturing - Industry 4.0 (Santos et al., 2017). Massive application of sensors, wireless communication and networks, more intelligent robots and machines and "big data" analytics – transform the manufacturing process in Europe (Brodeur et al., 2022).

In fact, "Industry 4.0" is a very broad term comprising: product development, production processes, efficiency and strategy, data management, relationship with consumers, and competitiveness, amongst others. While most academic works study specific technologies implementation, sector, or process digitalization, only a few authors focus on the management perspective in the enterprise. Strange and Zucchella (2017) and Piccarozzi et al. (2018) offer review of the principal organizational issues. However, the management literature still needs well-defined strategy based on the critical factors for the efficient digital transformation of the industrial companies.

Also, advanced, digital manufacturing technologies can unlock the circularity of resources with supply chains, even though the connection between circular economy and Industry 4.0 has not been well explored so far (Lopes de Sousa Jabbour et al., 2019).

This article takes a new approach to systematizing the implications of Industry 4.0 adoption with the goal to explore its relations with the circular economy performance of companies. The objective is contribute to the academic research, but also to help SMEs in the process of their digital transition.

To achieve it, first, we aim to assess whether the critical success factors, as previously defined in academic literature for Industry 4.0 implementation (Varbanova et al., 2022) correspond to the industrial manufacturing and agri-food context of SMEs in Central and Eastern Europe. Secondly, we explore the key strategic factors for both manufacturing and the agri-food sectors, taking into account Agriculture 4.0 infancy and the lack of studies addressing this issue. Besides, smart farming technologies have a strong potential to improve the economic performance of the sector, contributing to more sustainable agriculture (Knierim et al., 2019).

In agreement with the study by Varbanova et al. (2022), digital transition and circular economy are reviewed in detail, considering the data collected in SMEs from the countries of the Visegrad Group (namely Czechia, Hungary, Poland and Slovakia), Serbia and Bulgaria. The empirical research focuses on SMEs managers' and owners' perceptions of the impact of digitalization adoption on circularity in the companies surveyed, with the aim of understanding their attitudes towards these two key trends. Moreover, this study identifies ways SMEs can progress and develop based on appropriate digitalization and sustainability strategies (Gupta & Vegelin, 2016), contributing to a recent conceptual framework (Tick et al., 2022) for the integration of these two trends in the practice of SMEs.

Therefore, our main research questions are:

RQ1. Which critical success factors for implementing Industry 4.0. in organizations are valid in practice for SMEs in Central and Eastern Europe?

RQ2. Do all the studied factors apply to the digital transition of SMEs companies in

Central and Eastern Europe in manufacturing, but also in the agri-food sector?

To achieve the objectives, a quantitative research method was used and the Exploratory Factor Analysis technique (particularly suitable to extract a few factors from many related variables to a more manageable number), followed by the Analysis of Variance (Independent Sample T-test – to check the mean-variance across two groups) were applied. The authors are aiming to contribute to filling the gaps in the management literature and to confirm the empirical significance of the critical success factors to be endorsed by management teams to quickly adapt and increase circular economy performance and competitiveness in Industry 4.0 business environment.

This paper is organized as follows: section 2 presents the literature review, which discusses the main concepts of Industry 4.0, critical factors for adoption and transition of the manufacturing and agri-food sectors towards circular economy. Section 3 describes the research methodology used in this study, then section 4 presents the results and discussions from these analyses. Finally, section 5 presents the conclusions.

2. LITERATURE REVIEW

Industry 4.0 is characterized by the horizontal and vertical integration of production systems driven by real-time data interchange; but also flexible manufacturing to achieve customized production. The components of Industry 4.0 include, but are not limited to cyber-physical systems, the internet of things, cloud manufacturing, and additive manufacturing (Varbanova et al., 2022).

As previously mentioned, academic literature is short of a theoretical comparison between traditional and digital management in SMEs (Johansson et al., 2017; Strange & Zucchella, 2017). Most authors study some management aspects related to technological advancements in the Industry 4.0 era. For instance, Almada-Lobo (2015) focuses on decentralization and control techniques; Prause and Atari (2017), and Barsegyan and Shinkevich (2020) suggest new business models for the manufacturing. Finally, Prause (2015), and Antonova and Stoycheva (2018) add open innovation or lean tools (Simeonova, & Nedyalkov, 2020).

Few studies try to integrate the three (3) sustainability aspects: social, economic, and environmental (or the triple bottom line (TBL) assessment criteria, introduced by Elkington in the mid-1900s) in their evaluation of smart manufacturing (Lopes, 2022).

Indeed, today the manufacturing industry is transforming from a linear to a circular economy. Practices of circular economy (CE) will result in retrofitting industries, thereby enabling them to be more efficient in reusing, remanufacturing, and reducing the waste of resources. The circular economy is based on three fundamental principles, namely “preserve and enhance natural capital,” “optimize resource yields” and “foster systems effectiveness" (Sariatli, 2017). The importance of integrating CE practices and digital technologies has been recognized by the academic community (Govindan & Hasanagic, 2018; Dantas et al., 2021). For example, a study by de Sousa Jabbour et al. (2018, 2019) integrated Industry 4.0 and CE principles suggesting six action areas that enable organizations to move towards the, namely reclaiming, retaining, and restoring the health of

ecosystems; extend the life-cycle of the products; removal of waste in the production and supply chain processes; extract bio-chemicals from organic waste; dematerialize and implement I-4.0 technologies.

The interconnection between the TBL sustainability goals and Industry 4.0 is presented in Figure 1.

The digital transition, however, has its specificities in various economic sectors. In agriculture, the term "Agri-Food 4.0" is an analogy to "Industry 4.0", coming from the concept of "Agriculture 4.0". The agri-food industry has been evolving progressively according to the technological development in the manufacturing sector characterizing Industry 4.0 (Medina & Miranda, 2019).

Smart farm activities are connected to the cloud, which contributes to better management performances and higher results in the industrial enterprise (Sommer, 2015; Wang et al., 2016), while realizing sustainable industrial value creation on all three sustainability dimensions- economic, environmental, and social. Sustainability in digitalized agri-food organizations, as described by Albiero et al., (2020) and Moldavska et al., (2017), could be related to energy and resource efficiency, increased productivity, and shortening of innovation, amongst others. Žemaitis (2014), suggest product traceability and transparency during the entire life-cycle of the product, and operational strategies (Gunasekaran et al., 2013) to achieve sustainable targets. The popular CE-based approaches for resolving the issues faced by the food sector consist of technology-based solutions, social and behavioral changes, and policy recommendations.

However, the extant scientific literature on Agri-food 4.0 lacks consistent focus on the CE concept. Industry 4.0 is strongly cited from 2014, while Agriculture 4.0 is only recently quoted. Maffezzoli et al. (2022) highlight that the implementation of digital

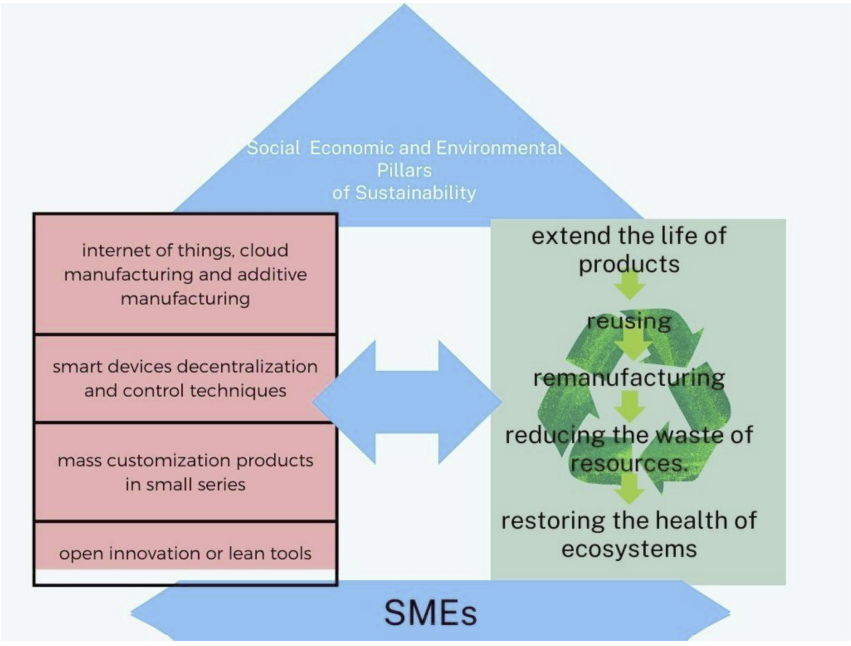

Figure 1. The interconnection between the TBL sustainability goals and Industry 4.0

solutions in the primary sector is not a trend, but aims to address current and future challenges, such as the need to make crops more efficient and effective and to evolve in an environmentally sustainable way. For example, a recent qualitative study exploring the factors intertwined in the adoption of Agriculture 4.0 suggested that regulatory pressure, cost optimization, increasing customers' concerns about health hazards, and intent to align supply and demand are key drivers.

In the Systematic Literature Review (SLR) conducted by Varbanova et al. (2022), following the PRISMA protocol, the critical success factors for Industry 4.0 included: (1) strong leadership; (2) well-defined management strategy; (3) adaptive organizational culture; (4) establishment of management information systems; (5) agile project management; (6) elevated level of cyber security; (7) cross- lined product life cycle and focus on consumer relations and finally, (8) respect of sustainability (in the form of circular economy) and regional specifics. Those were ultimately used as the reference factors explored in the present study. The next section will explain the methodological procedures.

3. RESEARCH METHODS

3.1. Sample and data

The research was conducted under the project "Possibilities and barriers for Industry 4.0 implementation in SMEs in V4 countries and Serbia". Research teams from the participating universities developed a self-administered questionnaire to collect data from SMEs in Hungary, Slovakia, the Czech Republic, Poland, Serbia, and Bulgaria. For the current analysis, the authors used the data collected between June and August 2021 in the six aforementioned countries, targeting specifically middle and top management executives in SMEs in Central and Eastern Europe. From the 635 valid respondents, 124 cases were selected (corresponding to small and medium-sized companies). From these, 34 cases were classified as SMEs from the agri-food sector, and the remaining 90 cases were assigned to other SMEs manufacturing sectors. Anonymity was ensured, and no personal information was required.

3.2. Questionnaire

The questionnaire was divided into different sections: information about the respondent and the company, level of technological implementation, knowledge, acceptance, and benefits from Industry 4.0 and sustainability.

For the current study, the choice of variables was based on the SLR study of Varbanova et al. (2022), which identified 8 critical success factors to serve as a base for implementing Industry 4.0 in a manufacturing organization. The questions on management strategy, leadership, organizational culture, resources (MIS; agile project management and cybersecurity systems are combined here), cross-lined product life cycle and focus on the consumer, business relations, and most importantly on circular economy, composed 21 variables (see full variable names in Table 1) presented in six groups (after combining them).

The researchers aimed to investigate the relationships between the 21 variables that focus on short-term plans for company digitalization, knowledge and resources, perceived benefits from Industry 4.0

Table 1. Critical implementation factors for Industry 4.0 (means and variables per factor)

Management strategy (Mean: 10.34)
1. The company is planning to digitalize its business processes to a higher level.
2. The company foresees introduction digital tools in the near future.
3. The company plans more investment for digitalization more in short-term.
4. The company already disposes with the necessary resources to apply more digitalized processes and services.
5. The company has the necessary knowledge to use more digitalized processes and services.
Leadership (Mean: 13.23)
6. In general, the organization is interested in digitalization and supports it.
7. Digitalized processes benefits employees' and the company performance.
8. Digital technologies contribute for the cost-effectiveness.
9. Digitalization increases the profit of the company.
Organizational culture (Mean 19.44)
10. Digitalization of the company makes work more interesting
11. Digitalization is a well-accepted by the workers in the company.
12. Digitalized processes and services increases productivity.
Resources - MIS; agile project management and cybersecurity
13. Digitalization decreases costs.
14. A specific person (or group) is available for assistance if difficulties with digitalization at the company arise
15. Digitalizing helps for the customized production.
Cross-lined product life cycle and focus on consumer/ business relations (Mean for Organizational culture 8.64 (combining Resources and Consumer/Business relations)
16. Business partners require more digitalization for our business.
17. There is a regulatory pressure for digitalization.
18. Customers require more digitalization of our business.
Circular economy (Mean: 21.11)
19. Digitalization contributes for extending the lifecycle of the products.
20. Digitalizing leads to less waste.
21. Digitalizing reduces carbon emissions from our business.
22. Our company has integrated SGDs into its long-term strategy.

technologies, processes, and methods, the Industry 4.0 challenges and perceived benefits for the businesses.

3.3. Research hypotheses

The theoretical review and the questionnaire provided input to assess the relevance of the suggested variables in the academic literature concerning digitalization. Consequently, the authors formulated 2 central hypotheses on Industry 4.0 critical success factors among SMEs in general in the Central Eastern European region.

H1. Pre-defined factors in literature have a positive impact on Industry 4.0 implementation in SMEs from Central and Eastern Europe.

H2. The pre-defined factors have the same positive impact on SMEs from the agri-food sector vis-à-vis other manufacturing industries in Central and Eastern Europe.

3.4. Data Analysis methods

The quantitative analysis was conducted using SPSS version 27. After some introductory descriptive analysis on the SME demographic profile, Exploratory Factor Analysis was carried out to find out the critical success factors of SMEs' digitalization. This type of analysis is based on correlations between variables and was

used in other academic studies related to Industry 4.0 to define critical success factors for implementation in enterprises (Wahl, 2015, Castelo-Branco et al., 2019).

Analysis of Variance (Independent Samples t-test) was carried out to test any significant differences between the manufacturing and agri-food sectors in relation to these implementation factors.

4. RESULTS

4.1. Demographic profile of the SMEs

From the 635 valid responses gathered, we have selected only cases from SMEs in the manufacturing and the agri-food sectors, which represented 124 valid responses. Of these, 26.6% were micro companies, 27.4 % were small companies and 46% were medium-sized companies. Most of the companies have annual revenues below 2 million euros (41.9%). Most of the enterprises (21.6%) are based in the Czech Republic; 20.2% in Poland and the same (20.2%) in Bulgaria; 14.5% are in Serbia; 12.2% in Slovakia, and 11.3% in Hungary. Furthermore, 19.3% (24 companies) are classified in the agri-food sector and the remaining 100 companies (80.7%) are in manufacturing. From the studied cases, 54.8% (68 companies) operate for more than 20 years in the sector (mature businesses) , and the other 55.2% (56 companies) operated for less than 20 years (including start-ups, youth growth, mature growth businesses).

4.2. Factor Analysis and Independent Samples t-test

We used three criteria to test whether Factor Analysis could be applied to our data: first, Bartlett's test of sphericity (significant p-value of <0.001 implies the rejection of the H_0 hypothesis of uncorrelated variables), meaning that the model fits the observed data. The second criterion was the acceptable measure of sampling adequacy (Kaiser-Meyer-Olklin (KMO) = 0.876) and the third criterion was the correlation matrix, which further confirmed the validity and high correlation between the variables. Communality (amount of variance explained by the factor solution) was higher than 30% for all the variables (Table 2) and the highest was for the short-term plans for Industry 4.0 implementation, whilst the lowest was for the inclusion of SDGs in the long-term strategy. Based on the factor loadings after rotation, five (5) factors were retained (Table 2).

These 5 factors correspond to the pre-defined factors from the literature review: 1) Management strategy, 2) Leadership and organizational culture, 3) Organizational culture (including implementation of MIS systems, cybersecurity etc.), 4) Business environment (including consumer relations) and 5) Circular economy. The reliability analysis was based on Cronbach's Alpha, and results for each factor were acceptable (higher than 0.7): "Leadership" (0.944); "Management strategy" (0.821), "Organizational culture" (0.893), "Circular economy" (0.803) and for "Business environment" (0.708).

Next, significant mean differences between the sectors agri-food and manufacturing were analyzed through Independent Samples t-test. Table 3 presents the results from the Levine's test and shows that equal variances are assumed.

Then, the analysis further confirms significant difference in mean for all the five

Table 2. Communalities and Related Component Matrix

Variables	Communalities	Rotated Component Matrix				
		F1	F2	F3	F4	F5
The company is planning to digitalize its business processes to a higher level.	834				0.789	
The company foresees introduction digital tools in the near future.	873				0.828	
The organization is interested in digitalization and supports it.	635				0.543	
The company already disposes with the necessary resources to apply more digitalized processes and services.	684					0.683
The company has the necessary knowledge to use more digitalized processes and services	772					0.709
A specific person (or group) is available for assistance if difficulties with digitalization at the company arise	653					0.618
Digitalized processes and services increases productivity.	855			0.867		
Digitalized processes benefits employees' and the company performance.	848			0.831		
Digital technologies contribute for the cost-effectiveness.	832			0.805		
Digitalization increases the profit of the company..	796			0.802		
Digitalization of the company makes work more interesting.	705			0.767		
Digitalization is a well-accepted by the workers in the company.	754			0.783		
Business partners require more digitalization for our business.	754		0.815			
There is a regulatory pressure for digitalization.	504		0.707			
Customers require more digitalization of our business.	651		0.598			
Digitalization contributes for extending the lifecycle of the products.	679	0.670				
Digitalizing leads to less waste.	728	0.770				
Digitalizing reduces carbon emissions from our business.	670	0.630				
Our company has integrated SDGs into its long-term strategy.	656	0.587				
Digitalization decreases costs.	676	0.694				
Digitalizing helps for the customized production	778	0.766				

Table 3. Independent Sample's t-test analysis

Factors	Levene's Test Sig.	Sig (2tailed)	Mean difference	Std.Error Diff.
Leadership	0.163	0.001	-3.262	0.928
Management Strategy	0.592	0.031	-1.518	0.686
Organizational culture	0.313	0.000	-4.234	1.014
Business environment	0.475	0.037	-1.446	0.728
Circular economy	0.478	0.000	-4.276	1.121

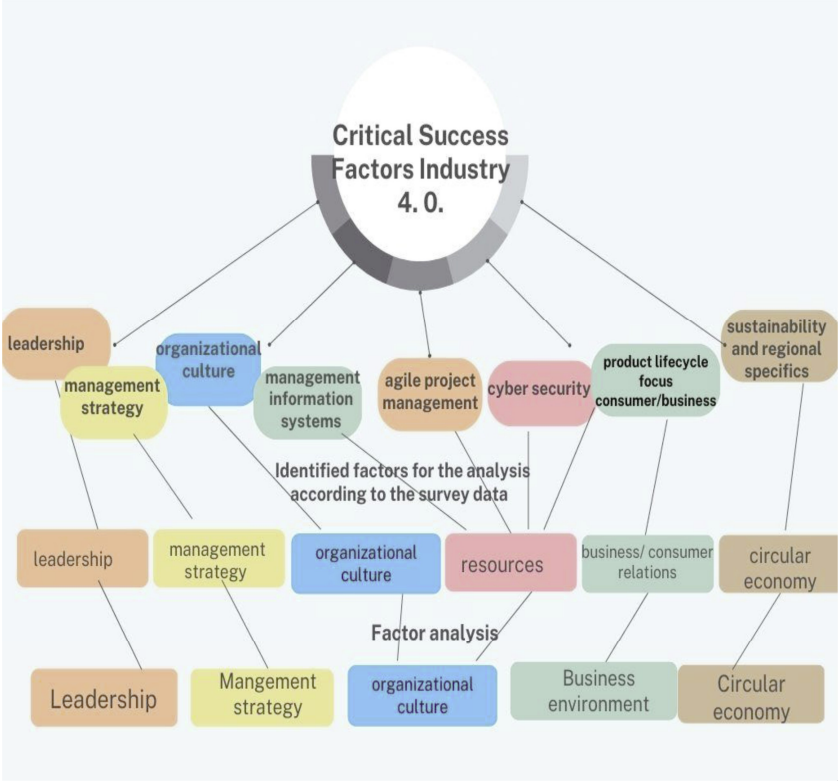

Figure 2. Critical success factors for Industry 4.0 implementation in SMEs in Central and Eastern Europe

factors *P*-Value < 0.05 (Table 3). The Confidence Intervals of the Difference present negative values for the factors and exclude 0, so we reject H_0 of equal means and we assume that means of agriculture for (1) Management strategy, (2) Leadership and organizational culture, (3) Organizational culture (including implementation of MIS systems, cybersecurity etc.), (4) Business environment (including consumer relations) and (5) Circular economy are significantly higher than for manufacturing.

5. DISCUSSION

H1. Pre-defined factors in the literature review have a significant positive impact for Industry 4.0 implementation for SMEs in Central and Eastern Europe.

The factor analysis with 21 variables revealed five (5) strategic factors with key importance for Industry 4.0 implementation in SME companies in Central and Eastern Europe. To answer the first research question: the factors that impact SMEs in Central and Eastern in their digital transition are: (1) "Management strategy", (2)"Leadership", (3) "Organizational culture" (including implementation of MIS systems, agile project management; cybersecurity etc.), (4) "Circular economy" and (5) "Business environment". They correspond to the pre-defined factors in the literature review by Varbanova et al. (2022), but also in number of other academic works (Bhatia & Kumar, 2022; Moeuf et al, 2020; Lopes de Sousa Jabbour et al., 2018; Dias et al, 2022). Then we fail to reject H1, confirming our hypothesis.

H2. The pre-defined factors have the same positive impact on SMEs from the agri-food sector and from other manufacturing industries in Central and Eastern Europe.

The main contribution of our study is the comparison of critical success factors for digital manufacturing to a specific industry sector- agri-food. To answer the second research question, the Independent Samples t-test test proved all of the five factors for Industry 4.0 implementations are also valid for the agri-food sector. Moreover, we observe significant differences in means for the latter. This means what the factors apply with higher strength for the agri-food sector. Therefore, we fail to reject H2.

6. CONCLUSION

This article contributes to the literature by empirically identifying critical success factors that are valid for the digital transition of SMEs in Central and Eastern Europe. The work is unique, as it addresses a significant gap in the knowledge of two comparatively recent concepts in academic literature – Industry 4.0 and Agri-food 4.0 and proves that the studied factors for the digital implementation in the manufacturing sector apply for the agri-food industry, but some of them with less extent.

The results from our study are promising and show that there are important steps to be considered by the management teams in an organization for Industry 4.0 (Agri-food 4.0) transition. They include a well-defined management strategy, strong leadership, organizational culture ready for change (also including the initial level of digitalization and human capital), the business environment (including not only business regulations, relations of the companies with partner organizations and subcontractors, but also the efforts towards the life-cycle development of the production to be centered on consumers expectations). Finally, among the drivers for the digital transition, circular economy of production in the manufacturing industries must be included in the organizational plans and aspirations.

Moreover, future studies could compare the preparedness for Industry 4.0 between Central and Eastern European companies and the more developed Western ones in the EU or to study additional factors with higher importance for the Agri-food 4.0 considering the sector's specifics.

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ИНДУСТРИЈА 4.0 ФАКТОРИ ИМПЛЕМЕНТАЦИЈЕ ЗА ПОЉОПРИВРЕДНА И ПРОИЗВОДНА МСП У ЦЕНТРАЛНОЈ И ИСТОЧНОЈ ЕВРОПИ

Monika Varbanova, Marcia Dutra de Barcellosa, Milena Kirova, Hans De Steur, Xavier Gellynck

Апстракт

У партнерству са пројектом „Могућности и баријере за имплементацију Индустрије 4.0 у МСП у земљама В4 и Србији“ – који је финансирао Вишеградски фонд, аутори су спровели истраживање у 124 мала и средња предузећа (МСП) у Централној и Источној Европи. Испитаници (средњи и топ менаџери) из Бугарске, Србије, Мађарске, Пољске, Словачке и Чешке су испитивани о стратешким факторима који утичу на дигитализацију. Анализирамо теоријске факторе на основу прегледа литературе и да ли су валидни у менаџерском контексту, не само за производњу, већ и за пољопривредно-прехрамбени сектор, где се сматра да је дигитална трансформација (Пољопривреда 4.0) у повоју. Резултати указују да су 21 променљиих, агрегираних тако да се формира пет (5) стратешких фактора (Лидерство, Стратегија управљања, Организациона култура, Пословно окружење и Циркуларна економија), од кључног значаја за имплементацију Индустрије 4.0 у организацијама. Поређење засновано на истраживачкој факторској анализи између производног и пољопривредно-прехрамбеног сектора резултира статистичким разликама за свих пет фактора. Ова студија доприноси литератури о менаџменту, а идентификовани фактори могу да усмере компаније да развију пословни модел који ће се применити у МСП компанијама у њиховој дигиталној транзицији.

Кључне речи: Индустрија 4.0, МСП, дигитализација, пољопривредно-прехрамбени сектор, паметна производња, стратешки фактори, анкета

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