INDUSTRY 4.0: ASSESSING THE LEVEL OF ADVANCED DIGITAL TECHNOLOGIES IN THE EU COUNTRIES USING INTEGRATED ENTROPY–TOPSIS METHODS

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Abstract
The fourth technological revolution has become a reality in many EU countries. The adoption of new advanced technologies such as artificial intelligence, cloud computing, 3D printing and robotics, the internet of things, and big data are drive pervasive transformations in the economy and society. Nevertheless, implementing advanced technologies based on Industry 4.0 is still a big challenge for many enterprises in the EU. Therefore, the purpose of this paper is the analyze the situation in the EU countries, and, particularly, the identification of differences in this respect between Old Member States (OMS) and New Member States (NMS). This study used a multi-criteria decision-making (MCDM) methodology based on the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to choose the best ranked EU country according to this issue. The obtained results provide an insight into the state of digitization in enterprises of each Member State. That could help policymakers on the EU level to identify areas requiring priority investment and strategic action.

Keywords: Industry 4.0, Advanced digital technologies, OMS, NMS

INTRODUCTION

The digital transformation of business and society in the EU has high growth potential across Europe. Today, the industry faces a new generation of fully digitalized companies (Capello & Lenzi, 2021). Three industrial revolutions are known: steam, electric, and digital, and the fourth industrial revolution, also called Industry 4.0, represents the „cyber-physical revolution“. It is characterized by genetic engineering, biometrics, and other advanced technologies such as the Internet of Things (IoT), Cloud computing, 3D printing and robotics, Artificial Intelligence (AI), Big data analysis (Castelo-Branco et al., 2019). Industry 4.0 implies complete digitalization of the production process, where the combination of human and artificial intelligence creates the conditions for modern and competitive production, from creating a product idea, through the organization of production and quality control, to the final industrial services. This concept not only raises quality but also reduces production costs (Masood & Sonntag, 2020; Nakagawa et al., 2021).

European industry can evolve based on the benefits of connecting Member States in the field of advanced digital technologies to take advantage of the range of opportunities offered by Industry 4.0 technologies. Support for the digitalization of industry and the development of Industry 4.0 is one of the priorities of the European Union. Hence, in advanced European countries, incentive funds are being established, and strategies and standards for digitalizing industrial processes are being adopted. European Commission observes Europe's overall digital performance and tracks the progress of EU countries, and based on those issues, and it determines the Digital Economic and Society Index (DESI) every year. The 2019 data in Figure 1 depicted the ranking of Member States according to the Digital Economy and Society Index.

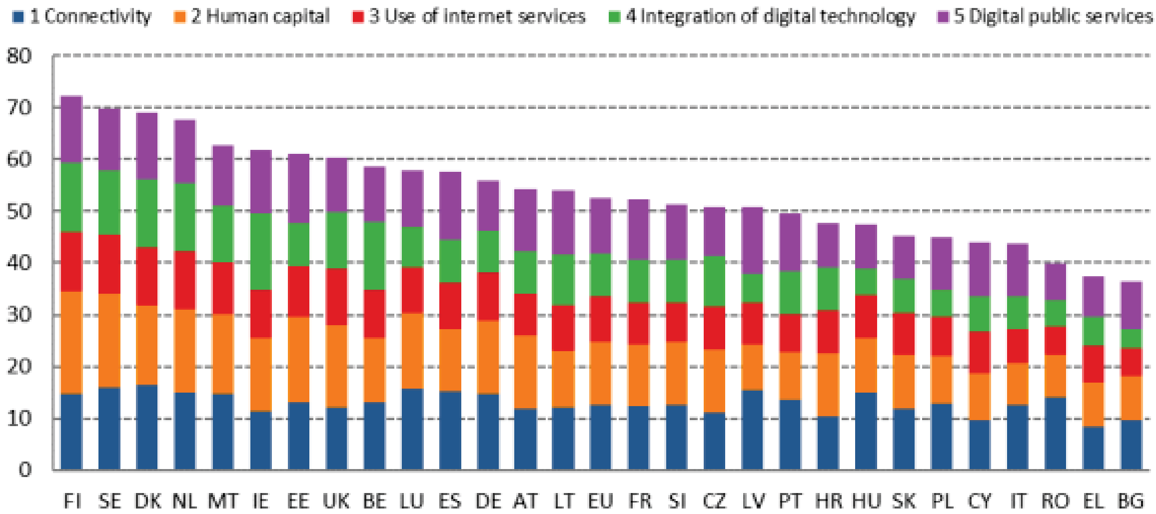

Figure 1. *Digital Economy and Society Index, 2020*
Source: DESI 2020, European Commission

Finland, Sweden, Denmark, and the Netherlands have the most advanced digital economies in the EU, followed by Malta, Ireland, and Estonia. On the other hand, the lowest scores have Bulgaria, Greece, and Romania (European Commission, 2020). Considering that there are differences between the OMS and NMS in the achieved level of using digital technologies in enterprises, the authors analyzed these differences separately in the paper. Therefore, this research deals with ranking EU countries according to the implementation of advanced digital technologies based on Industry 4.0. For ranking the EU countries a multi-criteria decision-making TOPSIS method was used (Dehdasht et al., 2020; Salehi et al., 2020).

EXPOSITION

To examine the defined goal of the study, the applied research model was illustrated in Figure 2. Based on the data collected within the World Bank's Enterprise Surveys (WBES), this research included the 27 economies of the European Union for the period from 2017 to 2020. Considering that the level and effects of the application of advanced digital technologies differ considerably between the EU countries, all countries were divided into Old Member States (Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden) and New Member States (Bulgaria, Croatia, Cyprus, Czech Republic, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Romania, Slovakia, Slovenia).

In the defined research model Shannon Entropy method was used to determine the weights of criteria (Hamsayeh, 2019). This method is based on the probability theory and is used to estimate unknown information or entropy. It is used to establish each criteria's objective weights because the weight of any criteria reflects its importance (Arsić et al., 2020). Criteria in the research model refer to advanced digital technologies used in enterprises such as 3D printing and robotics, artificial intelligence, big data analysis, cloud computing services, and the Internet of things.

The TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) was used as an appropriate method for ranking two observed groups of countries (alternatives in the model) according to defined criteria. This technique is one of the most popular MCDA methods which enables efficient computation of relative importance for each alternative and understandable interpretation of results (Salehi et al., 2020).

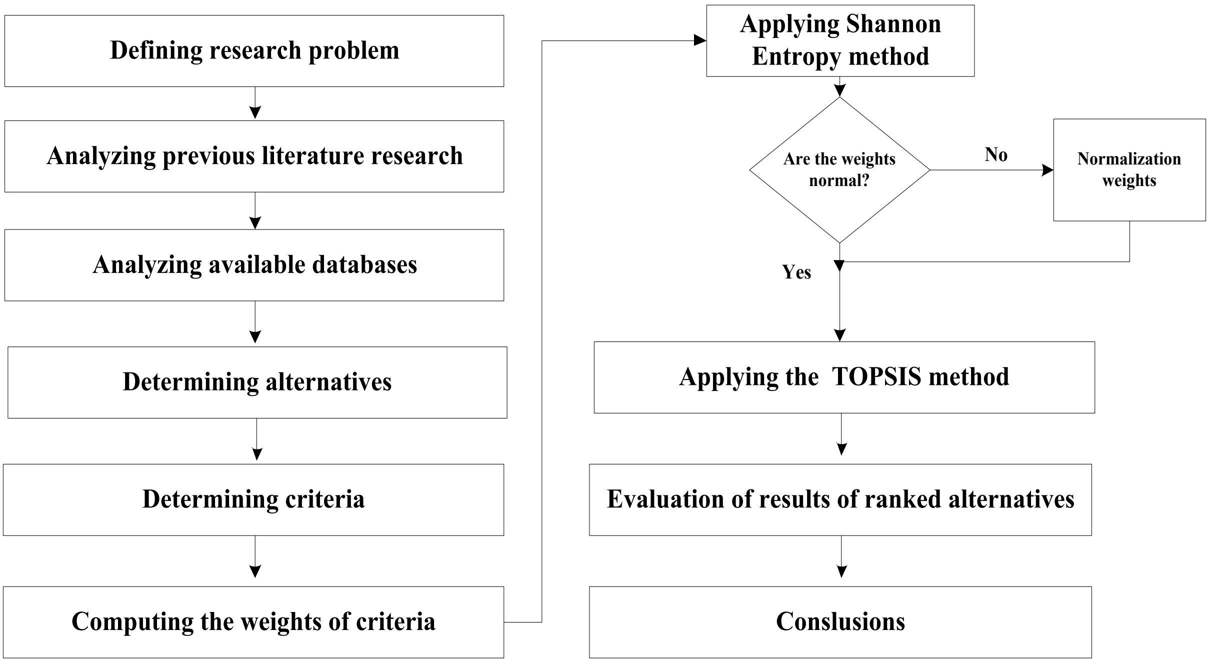

Figure 2. *Defined research model*
Source: Author's

According to this method, the best alternative should have the longest distance from the negative ideal solution and the shortest distance from the positive ideal solution (Lai et al., 1994; Ertugrul & Karakasoglu, (2007). The procedure of the TOPSIS method is consists of five steps, which is presented below (Hwang & Yoon, 1981):

Step 1. Construct the normalized decision matrix.

$$r_{ij} = x_{ij} / \sqrt{\left(\sum x_{ij}^2\right)} \; for \; i = 1,..., m \; ; \; j = 1,..., n \qquad (1)$$

where x_{ij} and r_{ij} are the original and normalized result of the decision matrix, respectively.

Step 2. Construct the weighted normalized decision matrix.

$$v_{ij} = w_j r_{ij} \qquad (2)$$

Step 3. Determine ideal and negative-ideal solutions.

$$A^+ = \{v_1^+ ,..., v_n^+\};$$
$$\text{where:} \qquad (3)$$
$$v_j^+ = \{\max(v_{ij}) \text{ if it is } j \in J' ; \min(v_{ij}), \text{if it is } j \in J''\}$$

$$A^- = \{v_1^- ,..., v_n^-\};$$
$$\text{where:} \qquad (4)$$
$$v_j^- = \{\min(v_{ij}) \text{ if it is } j \in J' ; \max(v_{ij}), \text{if it is } j \in J''\}$$

Step 4. Calculate the separation measure (Euclidean distance).

- Ideal separation:

$$S_i^+ = \left[\sum \left(v_j^+ - v_{ij}\right)^2\right]^{1/2} \quad i = 1, ...m \qquad (5)$$

- Negative-ideal separation:

$$S_i^- = \left[\sum \left(v_j^- - v_{ij}\right)^2\right]^{1/2} \quad i = 1, ...m \qquad (6)$$

Step 5. Calculate the relative closeness to the ideal solution.

$$C_i^* = S_i^- / (S_i^+ + S_i^-) \qquad (7)$$

where the obtained value Ci* must fulfill the condition: 0<Ci*<1. If the obtained value is higher (closer to 1), the effect of the alternative is better.

RESULTS AND DISCUSION

The computed information for the objective weights of each criteria for OMS is shown in Table 1, while the calculated weights for NMS are shown in Table 2.

Table 1. The Entropy weights calculations of the given criteriafor OMS

Criteria→ ↓Alternatives	3D printing and robotics	Artificial intelligence	Big data analysis	Cloud computing services	Internet of Things
Belgium	-0.20162	-0.18207	-0.21390	-0.19671	-0.19056
Denmark	-0.23214	-0.24050	-0.22077	-0.21380	-0.19372
Germany	-0.21238	-0.18207	-0.19553	-0.16928	-0.17738
Estonia	-0.15123	-0.15772	-0.15721	-0.20051	-0.17738
Ireland	-0.15123	-0.18207	-0.21390	-0.19414	-0.18076
Greece	-0.12021	-0.12995	-0.17517	-0.14418	-0.15954
Spain	-0.19019	-0.20370	-0.14758	-0.15869	-0.18076
France	-0.17805	-0.20370	-0.20677	-0.16023	-0.17044
Italy	-0.19019	-0.20370	-0.15245	-0.20423	-0.19372
Netherlands	-0.20162	-0.18207	-0.22737	-0.19671	-0.18408
Austria	-0.19019	-0.18207	-0.15245	-0.17651	-0.18076
Portugal	-0.17805	-0.20370	-0.16640	-0.16329	-0.18408
Finland	-0.21238	-0.20370	-0.20310	-0.22289	-0.25644
Sweden	-0.20162	-0.15772	-0.17942	-0.21726	-0.19056
SUM	-2.61108	-2.61473	-2.61203	-2.61845	-2.62020
Ej	0.98940	0.99078	0.98976	0.99219	0.99285
Dj	0.01060	0.00922	0.01024	0.00781	0.00715
Wj	0.23554	0.20474	0.22753	0.17346	0.15874
Weight (%)	23.55	20.47	22.75	17.35	15.87

Source: Authors' calculations

Based on the calculation of the weight of criteria for OMS using the Entropy method, 3D printing, and robotics with a dominant weight of 0.24 has the highest priority. The next was Big data analysis with a weight of 0.23, on the other hand, the criteria Internet of Things had the lowest priority with a value of 0.16 (Table 1).

Table 2. The Entropy weights calculations of the given criteria for NMS

Criteria→ ↓Alternatives	3D printing and robotics	Artificial intelligence	Big data analysis	Cloud computing services	Internet of Things
Bulgaria	-0.19472	-0.19767	-0.19407	-0.19157	-0.19719
Czech Republic	-0.20136	-0.19767	-0.19701	-0.19728	-0.20756
Croatia	-0.19918	-0.20243	-0.20085	-0.20038	-0.18782
Cyprus	-0.20136	-0.19279	-0.19109	-0.19915	-0.20318
Latvia	-0.19245	-0.19279	-0.19506	-0.19476	-0.20465
Lithuania	-0.19472	-0.20243	-0.19701	-0.19790	-0.19870
Luxembourg	-0.19696	-0.19767	-0.20461	-0.19728	-0.18782
Hungary	-0.19472	-0.19279	-0.19407	-0.19602	-0.19256
Malta	-0.20566	-0.20243	-0.21546	-0.20464	-0.20465
Poland	-0.19472	-0.19767	-0.19603	-0.19571	-0.19412
Romania	-0.19245	-0.19279	-0.19209	-0.19317	-0.19256
Slovenia	-0.19918	-0.19279	-0.19309	-0.20038	-0.19719
Slovakia	-0.19696	-0.20243	-0.19309	-0.19634	-0.19566
SUM	-2.56446	-2.56440	-2.56352	-2.56458	-2.56365
Ej	0.99981	0.99978	0.99944	0.99986	0.99949
Dj	0.00019	0.00022	0.00056	0.00014	0.00051
Wj	0.11858	0.13328	0.34643	0.08880	0.31290
Weight (%)	11.86	13.33	34.64	8.88	31.29

Source: Authors' calculations

The Entropy weights for NMS were determined also using the Shannon entropy and indicate that Big data analysis with a weight of 0.39 had the highest priority, then the Internet of Things with weight 0.31, while the criteria Cloud computing services had the lowest priority with a weight 0.26 (Table 2).

Application of TOPSIS method for ranking OMS and NMS, which was based on objective entropy weights, produced the following results (presented in Table 3 and Table 4, respectively) for the calculated values of Ideal Separation (Si+), Negative-Ideal Separation (Si-), and Relative Closeness to the Ideal Solution (Ci*).

The Relative Closeness to the Ideal Solution (Table 3) showed that the best ranked alternative for the OMS is Finland, followed by Denmark and Netherlands (Ci* =0.766, 0.658, and 0.482, respectively).

Table 3. The results of TOPSIS ranking for OMS

Alternatives	Si^+	Si^-	Ci*	Rank
Belgium	0.121680217	0.111655578	0.479	4
Denmark	0.09082369	0.174523296	0.658	2
Germany	0.138342449	0.103792016	0.429	6
Estonia	0.174845085	0.052200484	0.230	13
Ireland	0.150508366	0.085405558	0.362	11
Greece	0.210759607	0.021913443	0.094	14
Spain	0.150050054	0.090163026	0.375	9
France	0.146012519	0.095585061	0.396	8
Italy	0.131175337	0.102456592	0.439	5
Netherlands	0.126737743	0.118048792	0.482	3
Austria	0.152917284	0.078579841	0.339	12
Portugal	0.144268592	0.085666387	0.373	10
Finland	0.055028403	0.179870094	0.766	**1**
Sweden	0.140145571	0.098196879	0.412	7

Source: Authors' calculations

The worst-ranked countries in OMS are Greece, Estonia, Austria (Ci* =0.094, 0.230, and 0.339 respectively). The results obtained for the worst ranked country - Greece can be taken with a grain of salt, because for this country the initial data were not complete. Namely, there was a lack of data for 3D printing and robotics, Artificial intelligence, and the Internet of Things.

Table 4. The results of TOPSIS ranking for NMS

Alternatives	Si^+	Si^-	Ci*	Rank
Bulgaria	0.217462927	0.077451443	0.263	8
Czech Republic	0.171359245	0.165690144	0.492	2
Croatia	0.205786252	0.096489002	0.319	7
Cyprus	0.225801365	0.123136524	0.353	6
Latvia	0.197078501	0.134283477	0.405	3
Lithuania	0.187532201	0.104302457	0.357	5
Luxembourg	0.18789636	0.12115666	0.392	4
Hungary	0.233736867	0.045553593	0.163	11
Malta	0.023585912	0.26317463	0.918	1
Poland	0.211835877	0.06683108	0.240	10
Romania	0.249904874	0.036594481	0.128	12
Slovenia	0.222761183	0.079357313	0.263	8
Slovakia	0.226396105	0.072898461	0.244	9

Source: Authors' calculations

When assessing the implementation of advanced digital technologies in enterprises in NMS the best ranked countes are Malta, Czech Republic, and Latvia (Ci* =0.918, 0.492, and 0.405 respectively). While on the other hand, the countries which are the worst ranked in relation to the application of digital technologies are Romania, Hungary, and Poland (Ci* =0.128, 0.163, and 0.240, respectively).

CONCLUSION

Given the importance of introducing advanced digital technologies into the business process, the EU is encouraging the development and uptake of these technologies so people and businesses can enjoy the full potential of the digital world. However, even though the digitalization of business based on Industry 4.0 across Europe is a growing trend, uptake and penetration are not uniforms in OMS and NMS.

Therefore, the present study was aimed to recognize the most developed countries within analyzed groups of countries. For that purpose, the integrated Entropy-TOPSIS method was used. The results indicate that the best-ranked countries are Finland in OMS and Malta in NMS, and the worst-ranked Greece and Romania, respectively. These results are in line with the best ranking countries according to the DESI index.

Insight into the mentioned issues has theoretical significance, primarily in increasing the knowledge fund on advanced digital technologies in the EU. Additionally, this study has practical implications. Insight into the state of digitization in enterprises of each Member State helps policymakers identify areas requiring priority investment and action.

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