sustainability

MDPI

Article

A Precondition of Sustainability: Industry 4.0 Readiness

Slavko Rakic, Marko Pavlovic and Ugljesa Marjanovic *

Faculty of Technical Sciences, University of Novi Sad, 21000 Novi Sad, Serbia; slavkorakic@uns.ac.rs (S.R.); m.pavlovic@uns.ac.rs (M.P.)
* Correspondence: umarjano@uns.ac.rs

Abstract: To achieve sustainability and further develop their businesses, manufacturing companies need to find an appropriate response to the frequent changes in customer demands, development of new technologies, and dynamic competition. One of the possible requirements for sustainability is the adoption of the Industry 4.0 paradigm. This paper aims to apply Industry 4.0 general readiness assessment methodology and social network analysis to find out the readiness level of Serbian manufacturing and how digital technologies interplay during the time. The results of this study show that wireless human-machine communication technologies initiated the digital transformation of Serbian manufacturing from non-users to basic readiness level. Secondly, manufacturing companies significantly invested in the Cyber-Physical Production System to increase the level towards high readiness. Finally, manufacturing companies in Serbia should consider investing in capabilities to adapt the Near real-time production control system if aiming to compete with competitors from developed countries. The main contribution of this paper is to show the general readiness level of manufacturing companies for digital transformation in transition economies.

Keywords: Industry 4.0; digital technologies; readiness model; social network analysis; manufacturing companies

check for updates

Citation: Rakic, S.; Pavlovic, M.; Marjanovic, U. A Precondition of Sustainability: Industry 4.0 Readiness. *Sustainability* **2021**, *13*, 6641. https://doi.org/10.3390/su13126641

Academic Editors: Josep Llach, Andrea Bikfalvi and Rodolfo de Castro

Received: 20 April 2021
Accepted: 9 June 2021
Published: 10 June 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Nowadays, manufacturing companies are conducting business in a market that is characterized by the constant and frequent changes in customer demands, development of new technologies, international value chains, and dynamic competition [1]. To achieve sustainability and further develop their business, manufacturing companies need to find an appropriate response to the previously mentioned issues in a way that will increase efficiency, reduce costs, improve agility and flexibility, and upgrade responsiveness and resilience of their production operations [2]. For many manufacturing companies, it seems that the answer lies in the adoption of the Industry 4.0 paradigm [3]. This implies building an interface between the physical and the digital space through the use of Industry 4.0 enabling technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), Cloud Computing (CC), Big Data, and Data Science [4–6]. The Industry 4.0 ecosystem could provide permanent communication and interaction amongst numerous internal and external objects [7].

Manufacturing companies that wish to adopt Industry 4.0 paradigm into their operations first need to assess the status of their operations (i.e., to determine the readiness and maturity of the company to implement Industry 4.0 concepts) [8]. This represents a starting point for the identification of strengths, priorities, opportunities, potential challenges, and the creation of comprehensive transition plans necessary to overcome multiple barriers on the road to Industry 4.0 concept fulfillment [8]. Although barriers on the path to Industry 4.0 exist, both for manufacturing companies from the developed and developing countries, their properties differ significantly since the characteristics and their sheer number are more substantial in developed countries [9–11]. Most of the relevant studies to date, however,

have been from developed countries, and longitudinal research has been significantly lacking. This research intends to shed light on the evolutionary path to adoption of Industry 4.0 concepts of manufacturing companies from developing countries (i.e., Republic of Serbia) as a precondition for sustainability by assessing the readiness index development and key digital technologies. In addition, this study aims to investigate the direct impact of Industry 4.0 on sustainability.

Thus, the question addressed in this research is "What is the readiness level for Industry 4.0 of manufacturing companies, and how do digital technologies interplay it during the time?" To answer this question, we conducted a two-wave longitudinal survey with companies from manufacturing sectors. As expected, the results show that manufacturing companies significantly increased their readiness level for Industry 4.0. As companies progressed along the path, the number of CPS digital technologies that needed to be implemented to increase the readiness level also increased. Moreover, Social Network Analysis shows the density of the companies' networks in 2015 and 2018. Additionally, this analysis shows the impact of digital technologies on the companies according to the firm's size. The application of SNA in Industry research 4.0 gives an innovative view of the digital transformation of the manufacturing sectors.

The remainder of the paper is structured as follows: a literature review is presented in Section 2. Section 3 describes the methodology used in this study. Section 4 presents the research results. In Section 5, research results are discussed. Finally, the paper concludes in Section 6 with identified limitations of the study and suggestions for further research are specified.

2. Literature Review

Technological innovations such as computerized automation, sensors, and actuators have been used in manufacturing companies for a long time and have enabled manifold benefits in the execution of operations. However, their full potential has not been achieved, due to restrictions in connectivity and integration amongst various technologies used in the manufacturing process [12]. The main challenge has been in the information systems deployed. They have used different communication interfaces and due to this fact, systems have not been able to establish a connection and the subsequent communication necessary for data exchange between them [13]. A possible solution for sustainability arrived with the Industry 4.0 paradigm and the development of its enabling digital technologies (e.g., CPS, IoT, CC). Industry 4.0 has a direct impact on sustainability, both positive and negative. For instance, integration of digital technologies into the manufacturing processes enabled effective connection and communication between technological innovations [14]. However, utilization of Industry 4.0 technologies also triggered increased energy consumption from sensors and machinery [14]. All the pros and cons of Industry 4.0 opened up new questions; for instance, what are the steps on the path towards Industry 4.0 adoption, or how would the implementation of enabling technologies impact their existing operations [3,15].

There is no definitive roadmap for the digital transformation of manufacturing companies [16]. Industry 4.0 is a relatively recent concept among academicians and practitioners from the manufacturing sector and the field is not properly standardized or broad, and lacks clear boundaries [17]. Potential barriers on the path to Industry 4.0 are lack of governmental regulation, high financial investments, the complexity of the technologies, lack of multidisciplinary practical knowledge, internal resistances to organizational changes, and lack of skilled workers [18]. Furthermore, a significant number of manufacturing companies are not certain about the Industry 4.0 concepts, technologies, and necessary actions to maximize eventual benefits and the implications to their businesses to achieve sustainability [19]. In addition, the path towards Industry 4.0 varies notably between developed and developing countries, among different industrial sectors, and among companies within the sectors [1,11,20].

Manufacturing companies, particularly the ones from developing countries, suffer from deficiencies in digital technologies that are an integral part of Industry 4.0. Hence,

they need to gain access to the required infrastructure and "know-how" through technology transfers, contracting research centers, staff training, internal research, and development investments in order to overcome technical challenges arising from updating systems that are already in place [21,22]. A crucial step on the track to the digital transformation of manufacturing companies is to determine their current position with regard to the Industry 4.0 concepts and then subsequently to be able to produce comprehensive transition plans for Industry 4.0 concept fulfillment [23]. Therefore, the use of readiness or maturity assessment models is advised [24] to guide companies and their stakeholders through the transition phase efficiently and systematically [25]. Maturity and readiness are used interchangeably in many cases to describe assessment models. However, for this research, we use the term readiness to signify "the state in which an organization is ready to accomplish a task" [26] in contrast to maturity that signifies "the level of evolution that an organization has accomplished concerning a task" [26]. Thus, readiness differentiates from maturity due to the notion that readiness is assessed before engaging in maturing processes, whereas maturity is assessed from the actual implementation onwards [23].

Both researchers and practitioners have developed different readiness assessment models [17,27–33]: for example, SPICE-based Industry 4.0-MM [27], Industry 4.0 readiness assessment tool [28], Industry 4.0 maturity model [19], Maturity Scoring Model [29], Industrie 4.0 Maturity Index [17], I4.0 general readiness assessment [31], etc. All models cover different focus areas such as Technology and Infrastructure, Governance and Cybersecurity, Organization, People and Culture, Value chain, and process Industry 4.0 Awareness [30]. Since key drivers of manufacturing transition in Industry 4.0 are digital technologies [34], this research examines the utilization of digital technologies as a first step in analyzing the readiness for Industry 4.0. Hence, we used the I4.0 general readiness assessment methodology developed by the Fraunhofer Institute for Systems and Innovation Research ISI [31]. The model applied in this study follows the readiness assessment methodology of the Fraunhofer ISI, which is confirmed in the many studies developed by the partners from the EMS consortium [31]. This model has the aims to assess the current situation in terms of implementation of advanced technologies in the different manufacturing sectors. The methodology combines digital technologies allocated within three technological fields. Therefore, it provides information on the digitalization readiness of individual manufacturing companies.

3. Materials and Methods

3.1. Data and Sample

This manuscript used data from the European Manufacturing Survey (EMS) [35]. EMS is carried out in the 17 European countries, which is coordinated by the Fraunhofer ISI from Germany [36–38]. This research used a data set from the Republic of Serbia, obtained in 2015 and 2018. The research was conducted between manufacturing companies (NACE Rev 2 codes from 10 to 33) with more than 20 employees. We obtained 280 and 240 valid responses in 2015 and 2018, respectively. The response rate in both research rounds was about 34%. Table 1 depicts the distribution of the manufacturing companies by size.

Table 1. Distribution of manufacturing companies by size.

Company Size	N	%
20 to 49 employees	217	41.7
49 to 249 employees	244	46.9
More than 250 employees	59	11.4
Total	520	100

The result depicts that about 41.7% of the manufacturing companies in the sample are small, having between 20 and 49 employees, while another 46.9% of the manufacturing companies have between 50 and 249 employees, and 11.4%, more than 250 employees. In

the share of the total sample, the highest share belongs to food production, followed by the production of fabricated metal products, except machinery and equipment, and the manufacture of rubber and plastic products, which together have 40.5% of the total sample. Furthermore, Table 2 presents the distribution of the manufacturing companies by sector.

Table 2. Distribution of manufacturing companies by sector.

NACE Rev 2.2	Manufacturing Industry	Share in Total Sample (%)
10	Manufacture of food products	17.7
25	Manufacture of fabricated metal products, except machinery and equipment	14.3
22	Manufacture of rubber and plastic products	8.5
28	Manufacture of machinery and equipment n.e.c.	6.2
14	Manufacture of wearing apparel	5.9
27	Manufacture of electrical equipment	5.7
23	Manufacture of other non-metallic mineral products	5.1
	Others	36.6

3.2. Readiness Assessment Methodology

This research uses Industry 4.0 general readiness assessment methodology developed by the Fraunhofer ISI [31]. The methodology is presented in Figure 1.

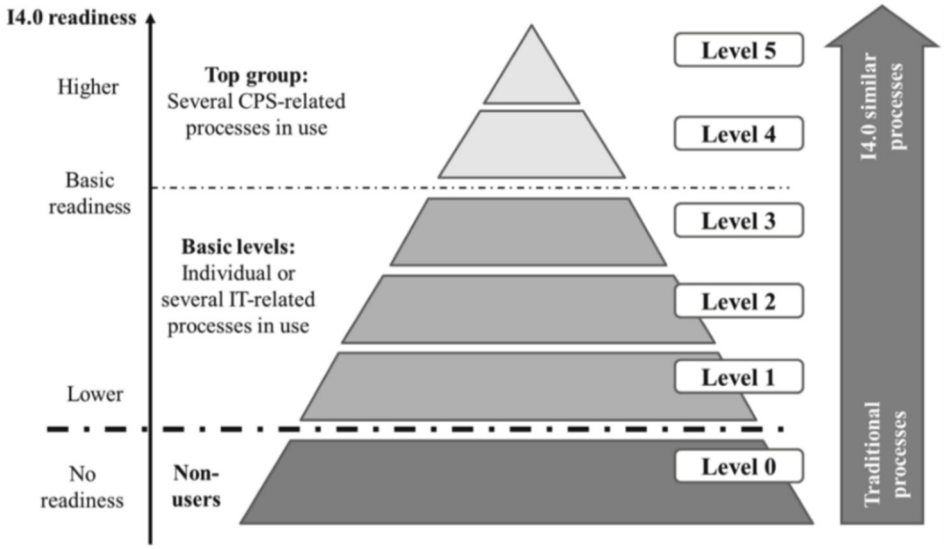


Figure 1. Levels of Industry 4.0 Readiness.

Industry 4.0 general readiness assessment research investigates seven digital technologies. They are combined into the following technology fields:

1. Digital Management Systems: The first field of technology consists of "Software system for production planning and control" and "Product Lifecycle Management Systems".
2. Wireless human-machine communication: In the second field of technology the "Digital Visualization" is combined with the "Mobile Devices".
3. Cyber-Physical Production System related processes: The third field of technology is the "Real-time production control system", the "Automation of internal logistics" and "Digital data exchange with customers and suppliers" together.

According to the approach, the manufacturing companies are divided into six levels according to the use of digital technologies:

- Level 0: Companies with a traditional process that do not use digital technologies

- Level 1: Companies that use digital processes in one of the three technology fields
- Level 2: Companies that use digital processes in two of the three technology fields
- Level 3: Companies that are active in all three technology fields and use both IT-related processes and a CPS-related process
- Level 4: Companies that are active in all fields of technology and use at least two technologies of CPS-related processes
- Level 5: Companies that are active in all technology fields and use at least three technologies of CPS-related processes.

Companies that are at level 0 are considered as non-users, at levels 1–3 as companies with basic readiness, and at levels 4 and 5 as high readiness enterprises.

3.3. Social Network Analysis

Social Network Analysis (SNA) is the method that investigates the relationship and position of actors in the social structures based on graph theory [39]. The SNA method is often used in the social sciences [40]. However, in the last decade research which investigated manufacturing sectors began to use it [41]. The studies from manufacturing sectors apply SNA to investigate the relationship between companies in the area of cloud manufacturing, logistics, digital servitization, and others [41]. SNA analysis provides a powerful methodology tool from social to technical sciences for investigation relations and ecosystems between the manufacturing sectors [39]. This research investigates the relationship between manufacturing companies and the use of digital technologies in the production process. According to the industry sectors, manufacturing companies are presented with red circles. Authors labeled digital technologies with a combination of letters and numbers ranging from DT1 to DT7 (i.e. DT1—Mobile/wireless devices for programming and operation of equipment and machinery, DT2—Digital solutions for providing drawings, work schedules, or work instructions directly on the shop floor DT3—Software for production planning and control, DT4—Digital Exchange of product/process data with suppliers/customers, DT5—Near real-time production control system, DT6—Systems for automation and management of internal logistics, DT7—Product-Lifecycle-Management-System (PLM) or Product/Process Data Management), and they are presented with blue squares. The snowball method is used for collecting data from surveys as the inputs for eigenvector and density analysis. For the evaluation and impact of the use of digital technologies in the manufacturing sector, eigenvector centrality is used. Furthermore, in the networks, authors take value 0 in the case where there is no network tie between manufacturing firms and use of digital technologies, and take value 1 where there is an existence network tie between manufacturing firms and the use of digital technologies. The SNA graphs present a network for the firms which are connected with digital technologies. Thus, these values are the input for the eigenvector and density analysis of the manufacturing firms.

4. Results

The analyses begin by presenting practices that are mostly adopted by the manufacturing companies followed by the Industry 4.0 general readiness of the Serbian manufacturing companies. Finally, the results of the SNA analyses with the graphs and eigenvectors are presented.

Table 3 presents the level of implementation of digital technologies by the manufacturing companies within the research. Table 3 reported that Serbian manufacturing companies in 2015 implemented the most Real-time production control system (31.9%), followed by Mobile devices (26.3%) and Automation of internal logistics (21.1%). The least implemented digital technology in 2015 is Digital data exchange with customers and suppliers (7.5%). In 2018, results indicate a vast change in the usage of digital technologies, especially within the technology field of Wireless human-machine communication. Almost half (46.6%) of the surveyed companies reported that they used Digital Visualization and 42.2 percent claimed that they used Mobile devices within the manufacturing plant. The

lowest utilization in 2018 was reported for the Digital data exchange with customers and suppliers (15.0%). All digital technologies increased the level of use from 2015 to 2018, except the Software system for production planning and control. As for the technology fields, the highest increase was noted in Wireless human-machine communication.

Table 3. Share of implemented digital technologies by technology field.

Technology Field	Digital Technology	Share in Total Sample (%)	
		2015	2018
Digital Management Systems	Software system for production planning and control	19.2	16.0
	Product Lifecycle Management Systems	12.2	28.6
Wireless human-machine communication	Digital Visualization	14.1	46.6
	Mobile Devices	26.3	42.2
Cyber-Physical Production System	Real-time production control system	31.9	33.5
	Automation of internal logistics	21.1	21.4
	Digital data exchange with customers and suppliers	7.5	15.0

The present study also investigated the readiness index of the Serbian manufacturing companies based on Industry 4.0 general readiness assessment. Table 4 portrays the distribution of the Industry 4.0 readiness levels of Serbian manufacturing companies. In 2015, the highest number of manufacturing companies was at Level 0 (49.77%). Results indicate that 43.66 percent of companies had a basic readiness index (Levels 1–3), and only 6.57 percent a high readiness index. In 2018, 30.1 percent of companies reported that they did not use any of the digital technologies studied and fully relied on traditional production processes (Level 0). More than half (51.94%) of the manufacturing companies achieved basic readiness and 17.96 percent a high readiness index.

Table 4. The Industry 4.0 general readiness of Serbian manufacturing companies.

Readiness Level	Share in Total Sample (%)	
	2015	2018
Level 0	49.77	30.10
Level 1	19.25	18.45
Level 2	21.13	26.21
Level 3	3.29	7.28
Level 4	2.35	10.19
Level 5	4.23	7.77
Non-users	49.77	30.10
Basic readiness	43.66	51.94
High readiness	6.57	17.96

By using the social network analysis, we investigated the level of use and the impact of digital technologies in Serbian manufacturing companies. Our research included seven digital technologies in the production process. Figure 2 presents the use of digital technologies in the manufacturing sector in the Republic of Serbia in 2015.

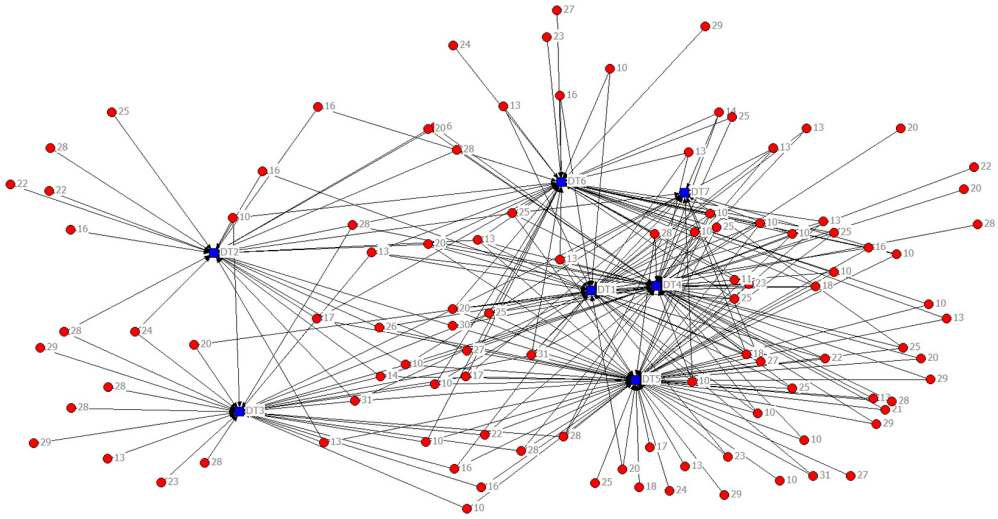


Figure 2. The use of digital technologies in the Serbian manufacturing sector in 2015.

The graph presents the use of digital technologies, which indicate no connectives between the industry sector of the company and digital technologies. However, it can be argued that similar companies use a DT1 and DT4, which is similar to companies that use a DT3. Until DT2, DT5, and DT7 there are no relations between companies and the use of these technologies. Table 5 shows the eigenvector of the use of digital technologies in the manufacturing sector in 2015 for small, medium, and large companies.

Table 5. Eigenvector of digital technologies in 2015.

Digital Technologies	Large Companies	Medium Companies	Small Companies
DT1	0.462	0.452	0.322
DT2	0.162	0.136	0.176
DT3	0.016	0.187	0.218
DT4	0.486	0.435	0.562
DT5	0.562	0.604	0.574
DT6	0.383	0.408	0.378
DT7	0.248	0.149	0.171

The results from Table 5 show that the Near real-time production control system, the Digital Exchange of product/process data with suppliers/customers, and the Mobile/wireless devices for programming and controlling facilities and machinery are the digital technologies with the highest eigenvector value in the large and medium companies. Additionally, the small companies have a high eigenvector value for the technologies based on the Systems for automation and management of internal logistics. Digital technologies with the lowest eigenvector value are Software for production planning and scheduling for large companies, Digital solutions to provide drawings, work schedules, or work instructions directly on the shop floor for the medium companies, and Product-Lifecycle-Management-Systems (PLM) or Product/Process Data Management for the small companies. Furthermore, the density of the network shows the values of 0.155 for the large companies, 0.181 for medium companies, and 0.211 for the small companies. Figure 3 depicts the use of digital technologies in the manufacturing sector in the Republic of Serbia in 2018.

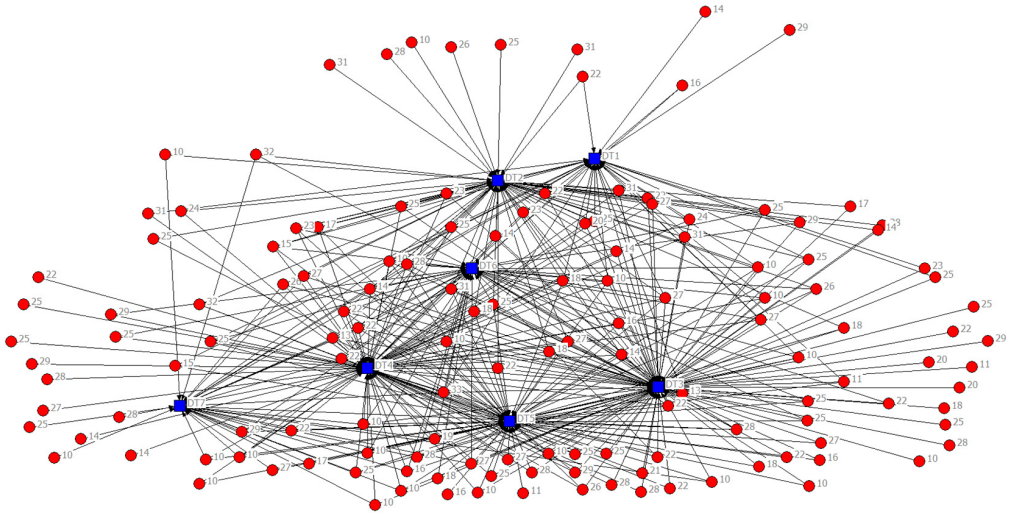


Figure 3. The use of digital technologies in the Serbian manufacturing sector in 2018.

The graph from the Serbian manufacturing sector in 2018 shows a stronger network than in 2015. Moreover, there are more relations between digital technologies and manufacturing companies. Nevertheless, there is no similarity between the industry sector of the companies and the use of any digital technologies. Results show that manufacturing companies have an individual approach to the use of these technologies. Table 6 presents the eigenvector of the use of digital technologies in the manufacturing sector in 2018 for small, medium, and large companies.

Table 6. Eigenvector of digital technologies in 2018.

Digital Technologies	Large Companies	Medium Companies	Small Companies
DT1	0.169	0.202	0.211
DT2	0.227	0.328	0.443
DT3	0.541	0.556	0.523
DT4	0.474	0.465	0.581
DT5	0.432	0.461	0.338
DT6	0.425	0.297	0.187
DT7	0.194	0.159	0.145

The results from Table 6 show that large and medium companies have the highest eigenvector values for the same digital technologies such as the Software for production planning and scheduling, the Digital Exchange of product/process data with suppliers/customers, and the Near real-time production control system. Additionally, the small companies have a high eigenvector value for the technologies based on the Digital solutions to provide drawings, work schedules, or work instructions directly on the shop floor. Digital technologies with the lowest eigenvector value are the Mobile/wireless devices for programming and controlling facilities and machinery for large companies, and the Product-Lifecycle-Management-Systems (PLM) or the Product/Process Data Management for medium and small companies. Furthermore, the density of the network shows values of 0.423 for large companies, 0.311 for medium companies, and 0.251 for small companies.

5. Discussion

This research empirically tested the Industry 4.0 general readiness assessment methodology developed by the Fraunhofer ISI [31]. Companies from all 24 manufacturing sectors (NACE Rev 2 codes from 10 to 33) were assessed to answer the research question "What is the readiness level for Industry 4.0 of manufacturing companies, and how do digital technologies interplay during the time?". Based on the results of the study it can be argued that

the general readiness of Serbian manufacturing companies transformed from non-users in 2015 to basic readiness in 2018. This was mainly triggered by the implementation of Wireless human-machine communication technologies. The reality of many manufacturing companies is to first invest available financial resources in technology such as digital visualization and mobile devices to achieve higher performance. For example, most of the manufacturing companies have a Wi-Fi connection on the shop floor and they might find it strategically convenient, and of great value to rather invest in wireless human-machine communication technologies instead of digital management or cyber-physical production systems. Therefore, manufacturing companies that have not started to incline themselves towards Industry 4.0 [27], could start using digital visualization or mobile devices within the plants to increase the level of general readiness towards Industry 4.0 and move closer to developed countries. For instance, in Germany, only 19% of manufacturing companies use mobile devices [31].

Further, Industry 4.0 has a direct positive impact on sustainability by improving manufacturing innovation [14]. Results indicate that the number of high readiness manufacturing companies tripled from 2015 to 2018 due to an increase in the implementation of Digital data exchange with customers and suppliers. This technology from the field of the Cyber-Physical Production System generated a higher level of general readiness towards smart manufacturing. Also, SNA results indicate that Digital data exchange with customers and suppliers had the highest impact on all other digital technologies in Serbian manufacturing companies, both in 2015 and 2018. This may be due to the fact that manufacturing companies have integrated their operations within digital supply chains. These results are in line with the previous research stating that Industry 4.0 can create unified sustainable production systems [42]. Since almost all digital technologies increased the level of use from 2015 to 2018 within the Serbian manufacturing domain, it can be argued that when all these technologies are put together, it might give opportunities to create a sustainable industrial environment.

Results indicate that the only drop from 2015 to 2018 was in the use of the Software system for production planning and control, from 19.2 to 16 percent, respectively. Compared to findings from manufacturing companies in Germany (67% in 2015), this represents the biggest difference. The reason behind low utilization may be that the manufacturing companies in Serbia had limited capability to adapt such systems due to connectivity requirements, and revision of software architectures [43,44]. SNA results indicate that medium and large companies have the highest eigenvector values for the same digital technologies in 2015 and 2018. Unlike small companies, which have different digital technologies with the highest values such as Digital solutions to provide drawings, work schedules, or work instructions directly on the shop floor in 2018 and Systems for automation and management of internal logistics in 2015. The Near real-time production control system is the digital technology with the highest eigenvector in all three groups of companies. Additionally, the density of the network increased in value from 0.155 to 0.423 for large companies, from 0.181 to 0.311 for medium companies, and from 0.211 to 0.251 for small companies. These results show that manufacturing firms use a higher number of the same digital technologies among the sectors. Moreover, SNA results show that manufacturing firms from the Republic of Serbia are strongly transforming their ecosystem from traditional to digital.

6. Conclusions

This paper identified a precondition for sustainability by assessing the general readiness of Industry 4.0 of manufacturing companies in Serbia. We defined a research question that was answered with results gained through the application of methodology developed by the Fraunhofer ISI coupled with the SNA method. The general readiness level of Serbian manufacturing companies for smart manufacturing altered from non-users to basic readiness in the period of three years, thus creating an opportunity for a sustainable industrial environment. The main findings of this study are:

- Wireless human-machine communication technologies initiated the digital transformation of Serbian manufacturing to a basic readiness level. Manufacturing companies found it strategically convenient to invest in digital visualization and mobile devices to accomplish sustainability.
- Manufacturing companies significantly invested in the Cyber-Physical Production System to increase the level towards high readiness. Digital data exchange with customers and suppliers had the highest impact on two other technology fields (i.e., Digital Management Systems, Wireless human-machine communication).
- Manufacturing companies in Serbia must consider investing in capabilities to adapt Software systems for production planning and control if aiming to compete with competitors from developed countries. This technology could increase the readiness level towards smart manufacturing.

The major limitation of this paper is that it considered all manufacturing sectors and company sizes. Future research could analyze the general readiness level of each of the manufacturing sectors (NACE Rev 2 codes from 10 to 33), and the readiness levels of small, medium, and large enterprises. Furthermore, it did not take into consideration the influence of economic crises in the previous two years. While the current paper explores the Industry 4.0 general readiness in the period from 2015 to 2018, a new longitudinal approach could give answers on how the coronavirus pandemic has influenced the use of digital technologies.

Author Contributions: Conceptualization, U.M. and S.R.; methodology, U.M., S.R. and M.P.; Analyzed the data: S.R. and M.P.; investigation, U.M., M.P. and S.R.; writing—original draft preparation, U.M., S.R. and M.P.; writing—review and editing, S.R. and U.M.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Science Fund of the Republic of Serbia under the Serbian Science and Diaspora Collaboration Program, project name "The Path towards Industry 4.0—Serbian Manufacturing" [grant number 6364339].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Djerdj Horvat from Fraunhofer ISI, Germany for providing valuable support. This paper also benefits from the comments of anonymous referees.

Conflicts of Interest: The authors declare that there is no conflict of interest.

References

1. Mittal, S.; Khan, M.A.; Romero, D.; Wuest, T. A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *J. Manuf. Syst.* **2018**, *49*, 194–214. [CrossRef]
2. Fatorachian, H.; Kazemi, H. A critical investigation of Industry 4.0 in manufacturing: Theoretical operationalisation framework. *Prod. Plan. Control.* **2018**, *29*, 633–644. [CrossRef]
3. Mourtzis, D.; Fotia, S.; Boli, N.; Vlachou, E. Modelling and quantification of industry 4.0 manufacturing complexity based on information theory: A robotics case study. *Int. J. Prod. Res.* **2019**, *57*, 6908–6921. [CrossRef]
4. Hermann, M.; Pentek, T.; Otto, B. Design principles for industrie 4.0 scenarios. In *Annual Hawaii International Conference on System Sciences*; Bui, T.X., Sprague, R.H.J., Eds.; IEEE Computer Society: Kauai, HI, USA, 2016; pp. 3928–3937.
5. Pavlović, M.; Marjanović, U.; Rakić, S.; Tasić, N.; Lalić, B. The Big Potential of Big Data in Manufacturing: Evidence from Emerging Economies. In Proceedings of the IFIP WG 5.7 International Conference, APMS 2020, Novi Sad, Serbia, 30 August—3 September 2020; Lalic, B., Majstorovic, V., Marjanovic, U., von Cieminski, G., Romero, D., Eds.; Springer Nature: Novi Sad, Serbia, 2020; Volume 592, pp. 100–107.
6. Bajic, B.; Suzic, N.; Simeunovic, N.; Moraca, S.; Rikalovic, A. Real-time Data Analytics Edge Computing Application for Industry 4.0: The Mahalanobis-Taguchi Approach. *Int. J. Ind. Eng. Manag.* **2020**, *11*, 146–156. [CrossRef]
7. Öberg, C.; Graham, G. How smart cities will change supply chain management: A technical viewpoint. *Prod. Plan. Control.* **2016**, *27*, 529–538. [CrossRef]
8. Becker, J.; Knackstedt, R.; Pöppelbuß, J. Developing Maturity Models for IT Management: A Procedure Model and its Application. *Bus. Inf. Syst. Eng.* **2009**, *1*, 213–222. [CrossRef]

9. Cardoso, W.; Azzolini Junior, W.; Bertosse, J.F.; Bassi, E.; Ponciano, E.S. Digital manufacturing, industry 4.0, clould computing and thing internet: Brazilian contextualization and reality. *Indep. J. Manag. Prod.* **2017**, *8*, 459. [CrossRef]
10. Frolov, V.G.; Kaminchenko, D.I.; Kovylkin, D.Y.; Popova, J.A.; Pavlova, A.A. The main economic factors of sustainable manufacturing within the industrial policy concept of industry 4.0. *Acad. Strateg. Manag. J.* **2017**, *16*, 1–11.
11. Rahimi, Y.; Matyshenko, I.; Kapitan, R.; Pronchakov, Y. Organization the information support of full logistic supply chains within the Industry 4.0. *Int. J. Qual. Res.* **2020**, *14*, 1279–1290. [CrossRef]
12. Xu, L.D.; Xu, E.L.; Li, L. Industry 4.0: State of the art and future trends. *Int. J. Prod. Res.* **2018**, *56*, 2941–2962. [CrossRef]
13. Gruhier, E.; Demoly, F.; Gomes, S. A spatiotemporal information management framework for product design and assembly process planning reconciliation. *Comput. Ind.* **2017**, *90*, 17–41. [CrossRef]
14. Sony, M. Pros and cons of implementing Industry 4.0 for the organizations: A review and synthesis of evidence. *Prod. Manuf. Res.* **2020**, *8*, 244–272. [CrossRef]
15. Zivanic, D.; Zelic, A.; Lalic, B.; Simeunovic, N.; Szabo, L. Improving the order picking efficiency by optimising the orders' sequence. *Int. J. Simul. Model.* **2019**, *18*, 125–137. [CrossRef]
16. Hughes, L.; Dwivedi, Y.K.; Rana, N.P.; Williams, M.D.; Raghavan, V. Perspectives on the future of manufacturing within the Industry 4.0 era. *Prod. Plan. Control.* **2020**, 1–21. [CrossRef]
17. Schuh, G.; Anderl, R.; Gausemeier, J.; ten Hompel, M.; Wahlster, W. (Eds.) *Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies (acatech STUDY)*; Herbert Utz Verlag: Munich, Germany, 2017.
18. Da Silva, V.L.; Kovaleski, J.L.; Pagani, R.N.; Silva, J.D.M.; Corsi, A. Implementation of Industry 4.0 concept in companies: Empirical evidences. *Int. J. Comput. Integr. Manuf.* **2020**, *33*, 325–342. [CrossRef]
19. Akdil, K.Y.; Ustundag, A.; Cevikcan, E. Maturity and Readiness Model for Industry 4.0 Strategy. In *Industry 4.0: Managing the Digital Transformation*; Springer: Cham, Switzerland, 2018.
20. Müller, J.; Dotzauer, V.; Voigt, K. Industry 4.0 and its Impact on Reshoring Decisions of German Manufacturing Enterprises. In *Supply Management Research*; Bode, C., Bogaschewsky, R., Eßig, M., Lasch, R., Stölzle, W., Eds.; Springer Gabler: Wiesbaden, Germany, 2017.
21. Da Silva, V.L.; Kovaleski, J.L.; Pagani, R.N. Technology transfer in the supply chain oriented to industry 4.0: A literature review. *Technol. Anal. Strat. Manag.* **2018**, *31*, 546–562. [CrossRef]
22. Birkel, H.S.; Veile, J.W.; Müller, J.M.; Hartmann, E.; Voigt, K.I. Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers. *Sustainability* **2019**, *11*, 384. [CrossRef]
23. Schumacher, A.; Erol, S.; Sihn, W. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia. CIRP* **2016**, *52*, 161–166. [CrossRef]
24. Proença, D.; Borbinha, J. Maturity Models for Information Systems—A State of the Art. *Procedia Comput. Sci.* **2016**, *100*, 1042–1049. [CrossRef]
25. Kohlegger, M.; Maier, R.; Thalmann, S. Understanding maturity models results of a structured content analysis. In Proceedings of the I-KNOW 2009—9th International Conference on Knowledge Management and Knowledge Technologies and Proceedings of I-SEMANTICS 2009—5th International Conference on Semantic Systems, Graz, Austria, 2–4 September 2009; pp. 51–61.
26. Pacchini, A.P.T.; Lucato, W.C.; Facchini, F.; Mummolo, G. The degree of readiness for the implementation of Industry 4.0. *Comput. Ind.* **2019**, *113*, 103125. [CrossRef]
27. Gökalp, E.; Şener, U.; Eren, P.E. Development of an Assessment Model for Industry 4.0: Industry 4.0-MM. In *Software Process Improvement and Capability Determination. SPICE 2017*; Mas, A., Mesquida, A., O'Connor, R., Rout, T., Dorling, A., Eds.; Springer: Cham, Switzerland, 2017.
28. Agca, O.; Gibson, J.; Godsell, J.; Ignatius, J.; Wyn Davies, C.; Xu, O. *An Industry 4 Readiness Assessment Tool*; University of Warwick: Coventry, UK, 2017.
29. Bittighofer, D.; Dust, M.; Irslinger, A.; Liebich, M.; Martin, L. State of Industry 4.0 Across German Companies. In Proceedings of the 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Stuttgart, Germany, 17–20 June 2018; pp. 1–8.
30. Wagire, A.A.; Joshi, R.; Rathore, A.P.S.; Jain, R. Development of maturity model for assessing the implementation of Industry 4.0: Learning from theory and practice. *Prod. Plan. Control.* **2021**, *32*, 603–622. [CrossRef]
31. Lerch, C.; Jager, A.; Maloca, S. *Mitteilungen aus der ISI-Erhebung*; Fraunhofer Institute ISI: Karlsruhe, Germany, 2017; pp. 1–12.
32. Horvat, D.; Stahlecker, T.; Zenker, A.; Lerch, C.; Mladineo, M. A conceptual approach to analysing manufacturing companies' profiles concerning Industry 4.0 in emerging economies. *Procedia Manuf.* **2018**, *17*, 419–426. [CrossRef]
33. Todorovic, T.; Lalic, B.; Majstorovic, V.; Marjanovic, U.; Tasic, N. General Readiness Assessment of Industry 4.0: Evidence from Serbian Manufacturing Industry. In Proceedings of the IFIP WG 5.7 International Conference, APMS 2020, Novi Sad, Serbia, 30 August–3 September 2020; Lalic, B., Majstorovic, V., Marjanovic, U., von Cieminski, G., Romero, D., Eds.; Springer International Publishing: Novi Sad, Serbia, 2020; Volume 591, pp. 139–146.
34. Kang, H.S.; Lee, J.Y.; Choi, S.; Kim, H.; Park, J.H.; Son, J.Y.; Kim, B.H.; Noh, S. Do Smart manufacturing: Past research, present findings, and future directions. *Int. J. Precis. Eng. Manuf. Technol.* **2016**, *3*, 111–128. [CrossRef]
35. Marjanovic, U.; Lalic, B.; Medic, N.; Prester, J.; Palcic, I. Servitization in manufacturing: Role of antecedents and firm characteristics. *Int. J. Ind. Eng. Manag.* **2020**, *11*, 133–144. [CrossRef]

36. Jager, A. European Manufacturing Survey. Available online: https://www.isi.fraunhofer.de/en/themen/industrielle-wettbewerbsfaehigkeit/fems.html (accessed on 10 April 2021).
37. Lalic, B.; Rakic, S.; Marjanovic, U. Use of industry 4.0 and organisational innovation concepts in the Serbian textile and apparel industry. *Fibres Text. East. Eur.* **2019**, *27*, 10–18. [CrossRef]
38. Lalic, B.; Marjanovic, U.; Rakic, S.; Pavlovic, M.; Todorovic, T.; Medic, N. Big data analysis as a digital service: Evidence form manufacturing firms. In Proceedings of the 5th International Conference on the Industry 4.0 Model for Advanced Manufacturin, Belgrade, Serbia, 1–4 June 2020; Lecture Notes in Mechanical Engineering. Wang, L., Majstorovic, V., Mourtzis, D., Carpanzano, E., Moroni, G., Galantucci, L.M., Eds.; Springer: Cham, Switzerland, 2020; pp. 263–269.
39. Borgatti, S.P.; Mehra, A.; Brass, D.J.; Labianca, G. Network Analysis in the Social Sciences. *Science* **2009**, *323*, 892–895. [CrossRef] [PubMed]
40. Rakic, S.; Tasic, N.; Marjanovic, U.; Softic, S.; Lüftenegger, E.; Turcin, I. Student performance on an e-learning platform: Mixed method approach. *Int. J. Emerg. Technol. Learn.* **2020**, *15*, 187–203. [CrossRef]
41. Zivlak, N.; Rakic, S.; Marjanovic, U.; Ciric, D.; Bogojevic, B. The Role of Digital Servitization in Transition Economy: An SNA Approach. *Tehnički Vjesnik Tech. Gazette* **2021**, in press. [CrossRef]
42. Ejsmont, K.; Gladysz, B.; Kluczek, A. Impact of industry 4.0 on sustainability-bibliometric literature review. *Sustainability* **2020**, *12*, 5650. [CrossRef]
43. Kozma, D.; Varga, P. Supporting digital supply chains by iot frameworks: Collaboration, control, combination. *Infocommunications J.* **2020**, *12*, 22–32. [CrossRef]
44. Ellwein, C.; Elser, A.; Riedel, O. Production planning and control systems—A new software architecture Connectivity in target. *Procedia CIRP* **2019**, *79*, 361–366. [CrossRef]